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16. Abstract

This is the final report for this project. The report briefly describes the six interim reports: (1) "Skidding Accident Systems Model", (2) "Factors Affecting Vehicle Skids: A Basis for Wet Weather Speed Zoning", (3) "Rainfall and Visibility - The View From Behind the Wheel", (4) "The Use of Rainfall Characteristics in Developing Methods For Reducing Wet Weather Accidents in Texas", (5) "Manual Guidelines For Skidding Accident Reduction", (6) "Treatments for Skid Prone Accident Sections - Evaluation of Effectiveness".

The primary purpose of this report is to reveal studies in (a) An Asphaltic Concrete Mix Design Technique for Predetermining Skid Resistance and (b) Equipment for Dynamic Superelevation Measurements. Stero-photo analysis procedures reported by Schonfeld were combined with an asphaltic concrete mix design method to allow the prediction of the SN_{40} value of the mix in the polished state. Also equipment was developed and fabricated to measure the cross-slope or superelevation at high speeds.

17. Key Words	18. Distribution Statement
Skidding Accident Reduction Asphalt Concrete Design Stereo-photo pavement analysis superelevation measurements cross-slope measurement	No Restrictions

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Two Aids for Field Personnel in Reducing Skidding Accidents

by

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Research Report 135-7F

Definition of Relative Importance of Factors Affecting Vehicle Skids

Research Study 1-10-70-135

Conducted by
Transportation Planning Division
Research Section
State Department of Highways and Public Transportation
In Cooperation With the
U.S. Department of Transportation
Federal Highway Administration
August 1975

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

Acknowledgments

The research reported herein was conducted under the supervision of Mr. John F. Nixon, Engineer of Research, and the general supervision of Mr. Phillip L. Wilson, State Planning Engineer.

This is the final report for the subject project and as such it should be noted that the work conducted in this project was accomplished by both the State Department of Highways and Public Transportation and Texas Transportation Institute. There were two co-supervisors in this project. Therefore acknowledgement is given to Dr. Don L. Ivey, one of the project supervisors and to numerous personnel at Texas Transportation Institute who performed a large portion of the research reported herein.

Acknowledgement is given to Mr. Brad Hubbard, Mr. C. L. Goss, Mr. B. D. Cannaday, Mr. C. D. Little, Mr. D. L. Edwards, Mr. James Wyatt and Mr. D. C. Minchey for the technical support received during this study.

Acknowledgement is given to Mr. Dereck J. Norwood who reviewed the previous interim reports and wrote several of the summaries found in Chapter II.

Mr. George Shute, Mr. Richard Zimmer, and Mr. Lionel Milberger designed and fabricated the Dynamic Slope Measuring Device reported herein and acknowledgement is given to the Texas Transportation Institute Electronics Section.

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Implementation

This project was developed to provide implementation for several projects which were studying skid resistance or wet weather accidents. For example, during the tenure of this project, data was used or combined from several projects studying the following:

1. Actual driver-vehicular maneuvers while passing other vehicles or negotiating horizontal curves.

2. Pavement, weather and tire factors affecting tire hydroplaning.

3. Pavement, weather and tire factors affecting skid resistance as measured with a skid test trailer.

4. Pavement, weather and tire factors involved in actual wet weather accidents.

5. The characteristics of pavement materials related to skid resistance.

Implementation has previously been submitted during the course of this project which:

1. Suggested wet weather speed zoning. A system was developed by which zoning could be accomplished and speed values determined.

2. Suggested minimum tread depths be established in the state. Data collected in this project and combined from other projects were submitted to document this need.

Implementation of data collected in this project which is presently being considered indicates the need for improved visibility in periods of inclement weather. It has been proposed that vehicle lights be activated during inclement weather.

Other items developed in this project and worthy of implementation are:

1. Use of an electronic instrument which activates a lighted sign when moisture or rainfall occurs; i.e. warning motorists of the danger of speed in wet weather driving conditions.

2. Use of the Dynamic Slope Measuring Device to inventory the superelevation of curves to denote curves in need of maintenance.

3. Use of the Asphaltic Concrete Mix Design Technique for predetermining skid resistance to check asphaltic concrete mix to determine if sufficient skid resistance will be available at the end of the service life of the mix. The technique should also be used to develop new mixes which meet the above criteria.

Summary

This report, as the final report for the subject project, summarizes six previous interim reports. This report also reveals research studies on (1) "An Asphaltic Concrete Mix Design Technique for Predetermining Skid Resistance" and (2) "Equipment for Dynamic Superelevation Measurements."

An asphaltic concrete mix design procedure was developed which combines Mr. R. Schonfeld's technique for predicting skid resistance from five texture variables and the Department's method of asphaltic concrete mix design. The results of the procedure were verified by obtaining skid resistance values on pavement surfaces for which the original mix design was obtained and revised by the newly developed procedure. An excellent relationship was found between the predicted SN_{40} values and the actual SN_{40} values measured by the trailer. It is believed that this procedure can be used to:

1. Study coarse aggregate blends.

2. Study local polishable aggregate materials for possible greater use.

3. Provide an extension to the present use of the British Wheel - Polish Value as a specification.

The Dynamic Slope Measuring Device shows a good relationship in values when compared to the slower mechanical measurements of cross-slope and superelevation. Many of the curves measured during correlation exercises did not contain "design" superelevation values. Also many of the curves show significant differences in superelevations on the same curve but in different directions. It should be noted that vehicles develop a transverse or cornering friction when negotiating a horizontal curve. Much of the needed transverse friction is reduced if superelevation is present. Deep soil movement and certain construction and maintenance practices can destroy or decay the design superelevation to the extent that curves can be dangerous when negotiated in wet weather at high speeds. The equipment described in this report can provide a rapid inventory of superelevation which can be used in planning maintenance activities.

I. Introduction

Background

This project was conceived to provide guidance to existing projects, combine information from existing or past projects in order to develop items for implementation, and to provide guidance for future needs - all within the area of vehicular skidding. At the time the project was initiated there were several HPR research projects concerned with vehicular skidding within the state and rapid advancement in skid resistance knowledge was made in many states and nations. FHWA was concerned that the Texas projects would overlap both in- and out-of-state projects. Also, there were many sub-areas in need of study and some direction was needed in developing priorities.

In order to provide direction in the study of vehicular skidding, two committees were established. One committee was composed of Project Supervisors with expertise in the subject area. The second committee was composed of field personnel within the Department. The Project Supervisors Committee provided internal direction and developed new procedures by combining previously developed work. The Departmental Committee assisted in developing priorities and experimenting with new procedures.

II. Interim Reports

Research Report 135-1 "Skidding Accident Systems Model"

A systems model was developed to characterize the factors affecting vehicular skidding. Particular emphasis was placed on wet weather conditions. Since an accident is defined as "an unexpected happening," it was believed that almost every event of vehicular skidding could be considered an accident. The skidding accident was subdivided into the following components:

1. the highway.
2. the vehicle.
3. the driver.

The meterological environment was assumed to influence each of the above components. Using the above components, with further subdivision, a systems model was developed which identified and classified the more significant elements in a skidding incident.

Research Report 135-2 "Factors Affecting Vehicle Skids: A Basis for Wet Weather Speed Zoning"

Immediately prior to this report, Galloway(1) had completed the first series of skid resistance tests using a skid test trailer in simulated rainfall conditions. The data indicated extremely low skid resistance with relatively smooth tires in moderate to heavy rainfall conditions. The skid resistance found was speed sensitive and it was believed that, considering economics, the most feasible method of reducing wet weather accidents was by reducing driving speeds. The report was developed as quickly as possible and offers an excellent example of combining information from other projects along with utilizing the expertise of researchers knowledgeable in different areas.

The method of establishing the suggested maximum wet speed was derived by equating the available friction at a site (pavement skid resistance) to the expected friction demand for a variety of expected vehicular maneuvers.

The SN_{40} value was modified by the expected tire tread depth, water film depth and tire pressure. Curves (equations) were included to determine the expected friction demand for stopping maneuvers, cornering maneuvers, passing maneuvers, emergency path-correction maneuvers and combined maneuvers. Critical speeds for hydroplaning were also included.

A process was recommended by which wet weather speed zoning could be implemented at selected sites.

Research Report 135-3 "Rainfall and Visibility - The View From Behind The Wheel"

Surveys of high-frequency wet weather accident sites have shown that visibility, in concert with undiminished traffic conflicts and speed, plays an important part in accident frequency. In order to develop appropriate measures to counteract this negative influence on traffic safety during inclement conditions, this portion of the study determines:

1. The frequency, duration and intensity of rainfall in the State of Texas.

2. The effect of different intensities of rainfall on drive visibility.

In determining the frequency, duration and intensity of rainfall, it was recognized that to obtain precise information regarding the probability of a motorist encountering rainfall of a given intensity, rainfall intensities as a function of time divided into intervals as small as one minute would have to be recorded at many geographical points for a period of years. Since this technique was deemed not economically feasible, reliance was placed on natural predictions made from less comprehensive data. From these data, a curve was extrapolated showing rainfall intensity in inches per hour verses minutes to represent the maximum rainfall variation that would occur within one hour. Also, an average rainfall intensity of one inch per hour was shown to occur during an average shower. Data shows that rainfall is comparatively rare in Texas; Central Texas having rainfall about 6% of the time. However, if the highway engineer designs with a rainfall intensity of 1/4 inch per hour (6.4mm/h), the design should be adequate 99.6% of the time.

In determining the effect of different intensities of rainfall on driver visibility, five field tests were run under the TTI rainmaker. A relationship was found and plotted for visibility verses rainfall intensity. Using equations taken from the curve and from other studies (i.e. Koschmieder), a series of curves were constructed to estimate the visibility of different objects under a range of rainfall intensities.

When the data on rainfall distribution and probability, and rainfall intensity effects on visibility, were combined, it was found that at an assumed rainfall intensity of 1 inch per hour a passing conflict occurs at speeds above 45 mph (72 km/h), considering the AASHO policy for passing distance and stopping distance.

A basis is presented whereby traffic engineers can logically select a "design" rainfall intensity based on the probability of a given event. Based on these "design" rainfalls, appropriate traffic speeds and/or maneuvers can then be determined for specific roadways and geographic areas.

Information developed in this report is adequate to justify reduced traffic speeds during periods of rainfall or to counter proposals for increased traffic speeds.

Research Report 135-4 "The Use of Rainfall Characteristics in Developing Methods for Reducing Wet Weather Accidents in Texas"

The objectives of the study reported herein were to:

1. Devise a method of determining approximate Percent Wet Times and calculating wet weather accident rates.

2. Devise a method of determining a design rainfall intensity.

In determining Percent Wet Time, Bell's method, as set forth in his paper "Computer Program for Analysis of the Frequency of Wet Pavement Curve Accidents" was used. A comparison was made between the Total Annual Rainfall at the selected measuring stations, as reported by the National Weather Service, and the Percent Wet Time at these stations, and a distinct correlation was found between the two variables. A method was devised, based upon the above relationship, to predict the Percent Wet Time using Total Annual Rainfall averages and a correlation curve. A Percent Wet Time for each county was then determined using Total Annual Rainfall for each county in conjunction with the correlation curve. Finally, an equation is presented whereby the Wet Weather Accident Rate can be determined based on such variables as Number of Wet Accidents, Daily Vehicle Miles and Wet Time Period of Study.

A method of determining a design rainfall intensity is reported based on measurements taken at eighteen weather stations arbitrarilly selected for study. At each station, the hourly records were studied for each month of 1969. The amount of precipitation falling during each hour of the day was recorded. The amount of hourly precipitation was considered to be the rainfall intensity in inches per hour.

The analyses consisted of establishing rainfall intensity groupings and recording the number of times during the year the hourly precipitation (intensity) fell in a specific group. By plotting the number of occasions on which a certain rainfall occurred verses the rainfall intensity, grouping estimates of "Percentiles of Occurrance" were established.

An 85th percentile was chosen, and an average of these was made for each of the eighteen locations. The average 85th percentile rainfall intensity based on a one hour measurement period was found to be 0.14 inch per hour (3.6mm/h). Because the amount of water measured over the period of an hour during a given rainfall would not reveal a case in which the rain might be very intense over a short period of time, it was decided to report rainfall intensity for a five minute duration. Data was found by which intensities of five minute durations could be extrapolated. Based on the 0.14 inch per hour (3.6mm/h) average discussed above, the 85th percentile intensity, over a five minute duration, was 0.50 inch per hour (12.7mm/h). This value is recommended for design use.

Research Report 135-5 "Manual - Guidelines for Skidding Accident Reduction"

This report was prepared in response to FHWA IM 21-2-73 which provided basic guidelines for a Skid Accident Reduction Program. This manual offers:

(1) guidelines for maintaining a skid resistance inventory; (2) a systematic procedure for the identification and correction of hazardous skid-prone locations; (3) an evaluation of current pavement design, construction and maintenance practices to provide adequate skid resistance properties for traffic needs; and (4) guidelines for preparation of an annual report on the skid accident reduction program.

The intent of this manual is to establish a systematic procedure for finding and correcting skidding accident prone sites and to insure an adequate, long-lasting skid resistant surface where surface construction is employed.

Research Report 135-6 "Wet-Weather Accident Reduction - A Benefit/Cost Approach"

In this report a method was developed to estimate the benefit/cost ratio of surface treatments to reduce wet road accidents. Thirty-six non-interstate rural highway control sections previously identified as "worst case" wet road accident sections were studied. Thirteen sections were eliminated from the study because of inadequate geometric or design characteristics, or for other indicated reasons. The remaining twenty-three sections were analyzed for benefits in accident reduction from renewal of surface friction.

A rapid identification of road sections experiencing a wet road problem can be made from accident records by establishing a statewide ratio of wet to dry road accidents and determining those sections with above average ratios. For the control sections studied, the number of accidents by type was multiplied by Burke's average accident costs to give the respective annual accident costs. The annual accident costs for each control section divided by the length in miles of each control section gave the accident costs per mile.

Using the above criteria for identifying sections in need of friction upgrading, and by incorporating such data as cost of resurfacing per mile and accident cost per mile, and using a multiplicative factor based on a ratio of accidents eliminated by resurfacing to the previous annual accident total for the section, an equation was developed to determine a benefit/cost ratio for friction upgrading of each of the sections. Each of the thirty-six sections originally selected for study are discussed in the appendix, and the benefit/cost ratios for each of the twenty-three resurfaced sections were calculated.

A chapter is devoted to alternative safety improvements for cases where geometric or design characteristics of the roadway prohibit improvement of wet accidents by resurfacing. The point is made that in these prohibitive cases, such as poor geometrics, an increase in surface texture may actually increase wet weather accident rates if such an improvement impels the driver to drive faster than the design speed.

A procedure is presented to aid field personnel in identifying road sections with wet road accident problems and determine the benefit/cost ratio of appropriate treatments.

III. Dynamic Superelevation Measuring Device

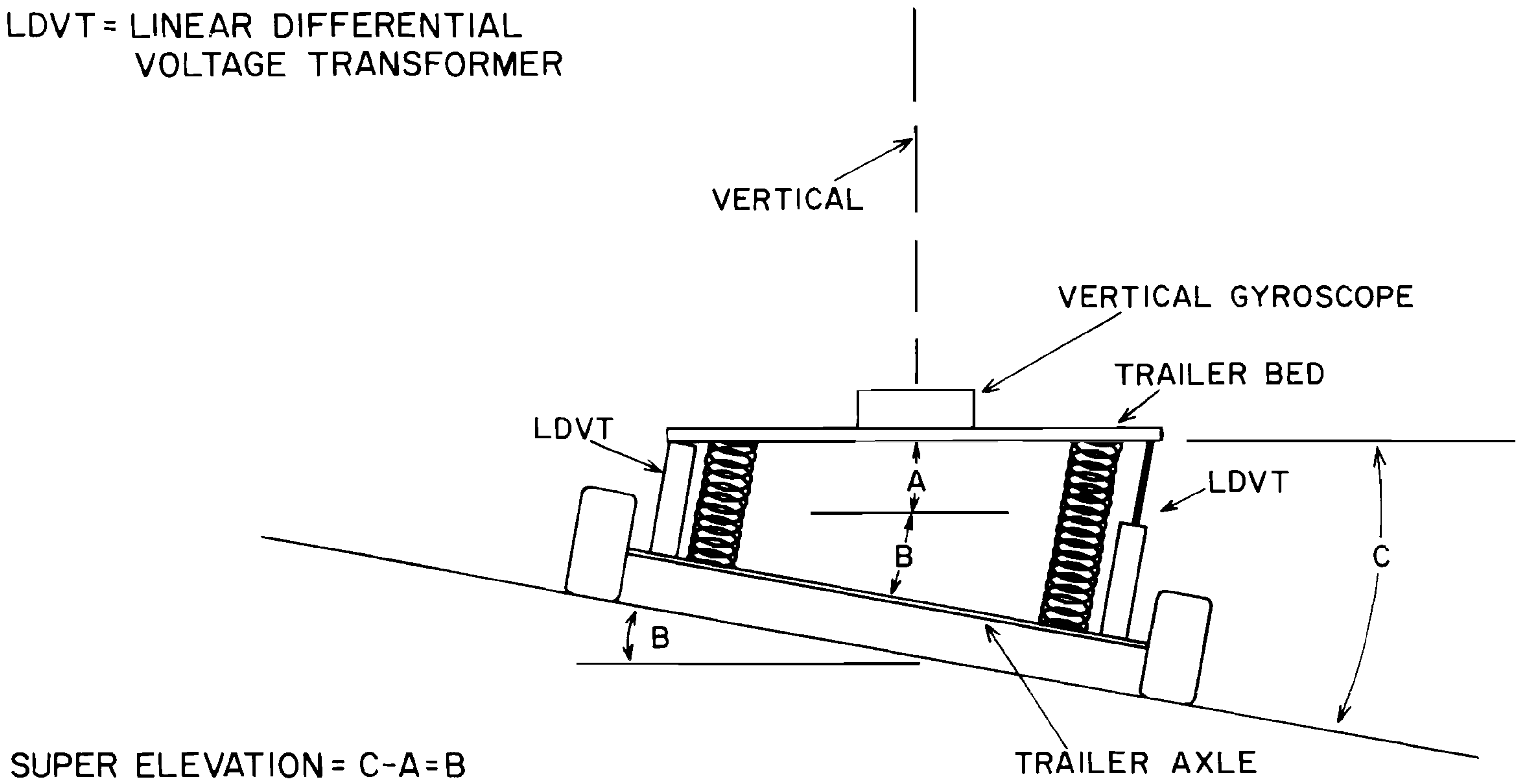
During the course of the project the Department's Engineer of Highway Safety requested a device be developed for rapid measurement of superelevation. Several wet weather accident sites had previously been studied in which zero or even negative superelevation was noted. It was believed that volumetric changes in the subgrade, and even construction overlay policies, caused superelevations to differ from the slopes developed during design and original construction. At certain sites, the small superelevation rates were believed to contribute to wet weather accident events.

Description of Equipment

The equipment used in this study was developed by the Electronics Section of Texas Transportation Institute. It was desired to dynamically measure the superelevation or cross-slope, preferably at a velocity of about 40 mph (64 km/h). It was further desired to install the measuring device on the skid test unit in order to obtain both skid resistance and transverse slope information simultaneously (or at least during the same period of time) in an inventory manner. The skid resistance information is obtained by an automated process which includes the activation of a switch (button) when a horizontal curve is involved. It was postulated that the slope measurements could be initiated when the horizontal curve switch was activated and could be reported along with the skid resistance information.

The cross-slope or superelevation can be measured as an angle between a horizontal line transverse to the highway and a line along the transverse slope of the highway surface. The line along the transverse slope is linear and disregards curved or parabolic slopes. This angle is also the angle between the horizontal and the centerline of an axle (or an imaginary line between the radius points of transverse wheels). Due to the suspension characteristics of a vehicle (or of a two-wheeled ASTM type skid test trailer), two dynamic angles are involved. Figure 1 is a schematic of the equipment and the angles involved. Note Angle B is desired and Angle B is equal to Angle C less Angle A.

The instrumentation consists of two Linear Differential Voltage Transformers (LDVT), a vertical gyroscope and an RZ package which outputs the electronic difference between Angle C and Angle A. The displacement difference between the two LDVT's and the distance between the LDVT's provides Angle C. The vertical gyroscope provides a vertical (or horizontal) reference and includes a rotary potentiometer which outputs voltage proportional to the inclination angle. The vertical gyroscope provides the angle between the horizontal reference and the transverse plane of the trailer bed or Angle A. The RZ package provides a D.C. voltage output proportional to Angle B or the superelevation (cross-slope) desired.



SCHEMATIC OF SLOPE MEASURING EQUIPMENT

FIGURE 1

Dynamically, or while towing the trailer at 40 mph (64 km/h), the Angles A, B and C are constantly changing; however, the response of the electronics is so rapid that the desired electronic output (Angle B) is available. The tires also bounce or exert a high speed vertical movement depending on the road profile which caused concern to the designers. Subsequent measurements indicate some high speed output (defined as "hash") which may be wheel bounce differential, but is of such a small extent, that it does not affect the desired values to be measured. This effect is shown in Figure 2. Note from the figure the recording device is a strip chart recorder in which a continual trace of transverse slope is available. Other devices capable of displaying, summarizing or treating D.C. voltages can be used, but a strip chart recorder was used throughout the study. Figure 2 shows a superelevation profile along the roadway where the roadway length is about 200 feet (61m). The figure indicates a superelevation which varies from about - 1°00' (1.75%) to about - 2°00' (3.49%). Table I allows a rapid conversion of transverse angle to transverse slope.

Figure 3 is a photograph of a model prepared for display at the Highway Short Course. The gyroscope and RZ package are housed in the metal box between the wheels of the model trailer. The two LDVT's are the cylindrical tubes mounted vertically near the coil springs. Figures 4 and 5 are photographs showing the mounting of the instrumentation in a skid test trailer. The metal box mentioned above was mounted near the center of the trailer parallel to the trailer bed.

The LDVT's were encased in a rubber boot and mounted near the trailer suspension.

Calibration is accomplished by:

1. Positioning the trailer on a level (horizontal) plane.

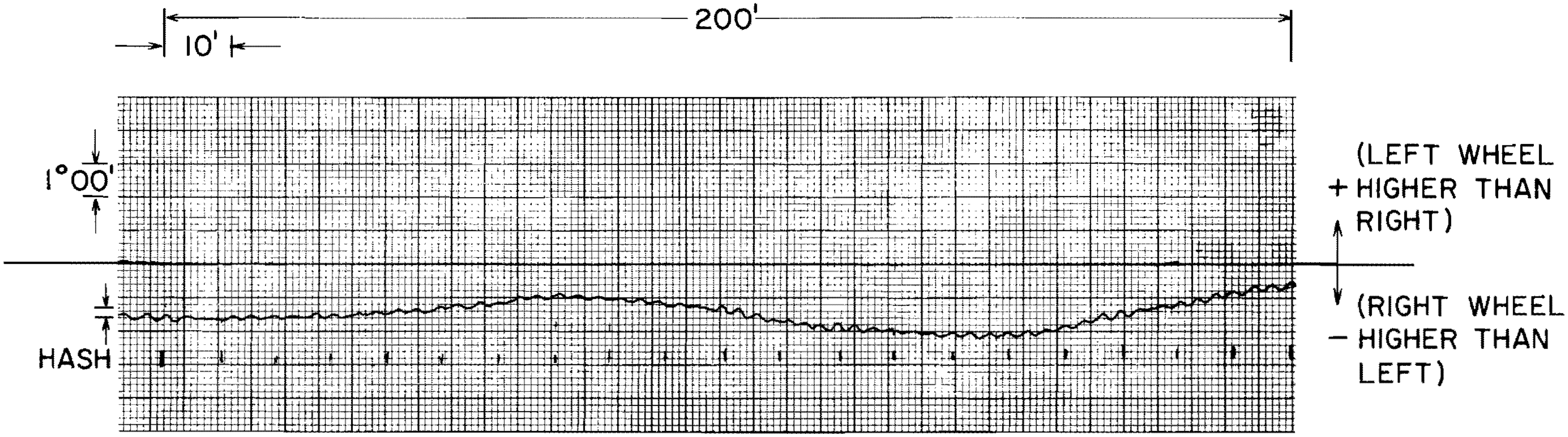
2. Zeroing the instrumentation (LDVT's vertical potentiometer and recorder).

3. Changing the transverse angle of the trailer bed by known amounts. This may be accomplished by using shims made of wooden blocks under the trailer wheels. Shims are used under both wheels alternately to calibrate recorder output which simulates both superelevation and cross-slope.

Further details about the instrumentation and calibration may be found in the appendices.

Evaluation of Equipment

The equipment was evaluated by studying the repeatability, day-to-day variation, variation due to tire pressure, and variation due to speed. To determine if the equipment measured the transverse slope accurately, the dynamic measurements obtained on known lengths were compared with manual (or mechanical) measurements over the same highway



EXAMPLE OF A DATA RECORD

FIGURE 2

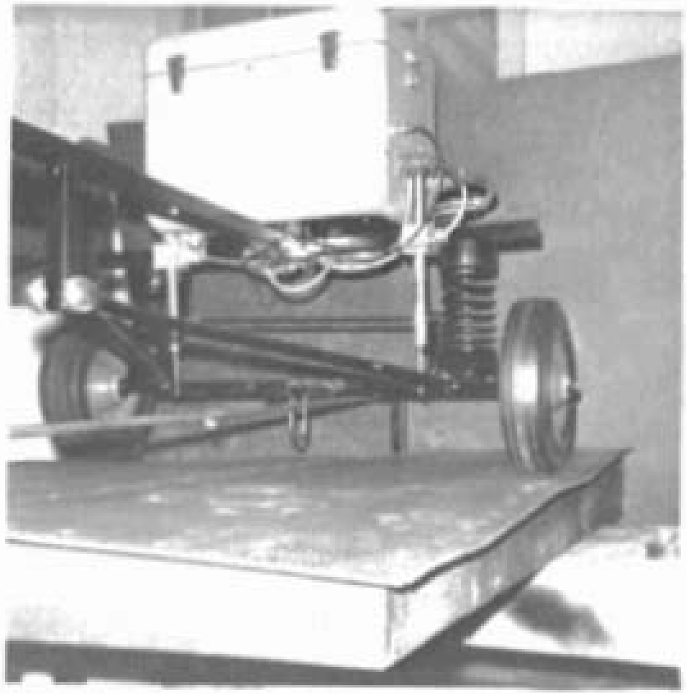
TABLE I
OF
CROSS SLOPE - SUPER ELEVATION CONVERSION

Angle	Rate of Slope *	Field Dimensions ** (in/ft)
0'	0	0
12'	.0035	1/32
24'	.0070	3/32
36'	.0104	1/8
48'	.0139	5/32
1°-00'	.0175	3/16
1°-12'	.0210	1/4
1°-24'	.0235	9/32
1°-36'	.0279	5/16
1°-48'	.0314	3/8
2°-00'	.0349	13/32
2°-12'	.0384	15/32
2°-24'	.0419	1/2
2°-36'	.0453	17/32
2°-48'	.0488	19/32
3°-00'	.0523	5/8
3°-12'	.0558	21/32
3°-24'	.0593	23/32
3°-36'	.0628	3/4
3°-48'	.0663	25/32
4°-00'	.0698	27/32
4°-12'	.0733	7/8
4°-24'	.0768	15/16
4°-36'	.0802	31/32
4°-48'	.0837	1"
5°-00'	.0872	1-1/16

*To convert to cm/m, move decimal two places to the right

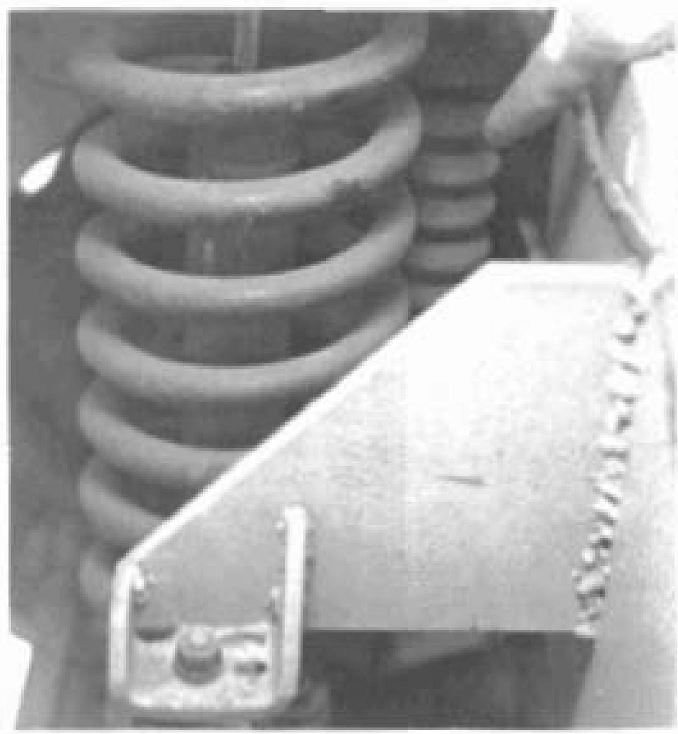
**To convert to cm/m, convert inches to decimal feet and move decimal two places to the right

Note:
This table permits rapid conversion of Angle to Rate of Slope to the Field Dimensions which are presently used by departmental field personnel.



Model of Dynamic Transverse Slope Measuring Device
Figure 3

Vertical Gyroscope
Figure 4



Linear Transformers
Figure 5

lengths. The mechanical device consisted of a 6-foot straight edge with carpenter level attached. The vertical distance from leveled straight edge to pavement surface was scaled and converted to transverse slope.

To accomplish the evaluation study, fifteen locations were selected on a variety of highway types. Twelve of the locations were near the center of horizontal curves and three locations were tangent sections. Generally, both directions were considered at each location. Therefore, with the exception of location number 14, two test sections were available at each location. Table II offers a list of the test sections along with other test data. The length of each test section was 200 feet (61m) and mechanical transverse slope measurements were obtained at intervals of 10 feet (3m).

Repeatability Tests

Tests for repeatability of the equipment were conducted by obtaining five tests at 40 mph (64 km/h) and 24 psi (165 kPa) tire pressure on two test sections. The five tests were collected one after the other as soon as the test passes could be obtained. Since the two test sections were on the same curve but in opposite directions, the tests were conducted rapidly. Table III shows the results of the study. The left column of the table contains the cross slope measurements obtained with the mechanical device at the 21 spots (10 foot (3m) intervals for a 200 ft. (61m) length). The next five columns are the corresponding dynamic cross-slope values obtained from the strip chart. The dynamic values were obtained at 10 foot (3m) intervals, corresponding to the location of the mechanical values, by marking the beginning and end of the test section while conducting the dynamic test, and dividing the strip chart into 20 equal segments.

A summary of Table III follows:

	Section #1 Eastbound (1EB)	Section #1 Westbound (1WB)
Average Dynamic Superelevation	3°15'	1°39'
Range of Superelevation Passes	0°20'	0°14'
Standard Deviation of Superelevation Passes	0°08'17"	0°05'10"

It may be noted in Figure 2 that the closest divisions on the strip chart are in millimetres and each millimetre represents 0°12'. Therefore the repeatability error is about the same as the accuracy of obtaining data from the analog records.

Day-to-Day Variation

The variation occurring from day-to-day was studied by obtaining tests at 40 mph (64 km/h) and 24 psi (165 kPa) tire pressure over four test sections on different days. Dynamic superelevation values were obtained from the analog chart at 10 foot (3m) intervals over the

TABLE II
DYNAMIC SLOPE MEASUREMENTS
TEST SECTION INFORMATION

Test Sect. No.	Curvature Inform. (Deg. of Curv.)	Pavement Type	Texture (Putty Impr.)	Design Superelevation Rate
1-WB	4°	Ty.D HMAC	.022	.05
1-EB	4°	Ty.D HMAC	.021	.05
2-WB	3°	Ty.D HMAC	.017	.04
2-EB	3°	Ty.D HMAC	.011	.04
3-WB	4°	Ty.D HMAC	.017	.05
3-EB	4°	Ty.D HMAC	.011	.05
4-WB	10°	Ty.D HMAC	.014	.08
4-EB	10°	Ty.D HMAC	.012	.08
5-WB	10°	Ty.D HMAC	.015	.08
5-EB	10°	Ty.D HMAC	.014	.08
6-NB	2°	Ty.D HMAC	.017	.04
6-SB	2°	Ty.D HMAC	.021	.04
7-NB	2°	Ty.D HMAC	.020	.04
7-SB	2°	Ty.D HMAC	.021	.04
8-NB	Tangent	Gr.4 S.T.	.071	-
8-SB	Tangent	Gr.4 S.T.	.052	-
9-NB	1°	Gr.4 S.T.	.021	.02
9-SB	1°	Gr.4 S.T.	.017	.02
10-NB	2°30'	Gr.4 S.T.	.062	.04
10-SB	2°30'	Gr.4 S.T.	.035	.04
11-NEB	Tangent	S.T.	.085	-
11-SWB	Tangent	S.T.	.084	-
12-NEB	5°	S.T.	.075	.05
12-SWB	5°	S.T.	.092	.05
13-NB	Tangent	Ty.D HMAC	.023	-
13-SB	Tangent	Ty.D HMAC	.026	-
14-NB	3°	S.T.	.059	.04
15-NEB	3°	S.T.	.088	?
15-SWB	3°	S.T.	.079	?

Note:
HMAC is hot mixed asphaltic concrete.
S.T. is surface treatment.
Table II indicates no relationship between transverse slope and texture. However, texture data is included should restudy or future reference be needed.

TABLE III
REPEATABILITY TESTS

40 mph
(64 km/h)

24 psi
(165 kPa)

Sect. #1-EB

Curve 4° Rt.
Type D HMAC (Limestone)

	MECH	DYNAMIC				
		BEB	BEB	BEB	BEB	BEB
	2°-56'	2°-33'	2°-50'	2°-48'	2°-50'	2°-54'
	2°-52'	2°-36'	2°-56'	2°-54'	2°-56'	2°-56'
	2°-52'	2°-42'	2°-58'	2°-56'	2°-58'	3°-00'
	3°-02'	2°-48'	3°-08'	2°-58'	3°-02'	3°-00'
	3°-14'	2°-57'	3°-18'	3°-10'	3°-12'	3°-12'
	3°-14'	3°-06'	3°-26'	3°-20'	3°-24'	3°-22'
	3°-30'	3°-18'	3°-38'	3°-26'	3°-36'	3°-28'
	3°-38'	3°-33'	3°-50'	3°-46'	3°-48'	3°-44'
	3°-40'	3°-39'	4°-06'	3°-54'	3°-58'	3°-54'
	3°-54'	3°-48'	4°-10'	4°-00'	4°-08'	4°-00'
	4°-08'	3°-48'	4°-04'	4°-04'	4°-04'	4°-06'
	4°-08'	3°-42'	4°-00'	4°-00'	4°-00'	4°-04'
	3°-52'	3°-30'	3°-46'	3°-48'	3°-50'	4°-00'
	3°-46'	3°-18'	3°-34'	3°-36'	3°-36'	3°-48'
	3°-32'	3°-06'	3°-26'	3°-26'	3°-28'	3°-34'
	3°-30'	2°-57'	3°-10'	3°-12'	3°-14'	3°-24'
	3°-12'	2°-37'	2°-54'	2°-56'	2°-58'	3°-06'
	2°-52'	2°-27'	2°-48'	2°-44'	2°-48'	2°-56'
	2°-44'	2°-22'	2°-40'	2°-36'	2°-40'	2°-42'
	2°-44'	2°-21'	2°-36'	2°-36'	2°-36'	2°-40'
	2°-36'	2°-15'	2°-34'	2°-34'	2°-36'	2°-38'
Mean	3°-20'	3°-01'	3°-20'	3°-16'	3°-19'	3°-21°
S.D.	0.478°	0.513°	0.525°	0.508°	0.512°	0.496°
S.D. (Minutes)	0°-29'	0°-31'	0°-32'	0°-30'	0°-31'	0°-30'

Average = 3.257° or 3°15'
Standard Deviation of Averages = 0.138° or 0° 08' 17"

Note:
MECH is the measurements obtained with the mechanical device.
BEB is the outside eastbound lane.

TABLE III (Cont.)
REPEATABILITY TESTS

40 mph
(64. km/hr)

Sect. #1 WB

Curve 4° Rt.
Type D HMAC (Limestone)

	MECH	BWB	BWB	BWB	BWB	BWB
	2°-00'	1°-50'	1°-38'	1°-40'	1°-40'	1°-40'
	2°-00'	1°-48'	1°-34'	1°-40'	1°-36'	1°-38'
	1°-46'	1°-45'	1°-28'	1°-36'	1°-36'	1°-36'
	1°-46'	1°-42'	1°-24'	1°-30'	1°-24'	1°-28'
	1°-38'	1°-30'	1°-18'	1°-22'	1°-18'	1°-20'
	1°-30'	1°-24'	1°-12'	1°-12'	1°-06'	1°-10'
	1°-18'	1°-12'	1°-00'	1°-02'	1°-04'	1°-04'
	1°-18'	1°-12'	1°-02'	1°-04'	1°-12'	1°-12'
	1°-30'	1°-21'	1°-10'	1°-12'	1°-20'	1°-14'
	1°-32'	1°-30'	1°-20'	1°-22'	1°-26'	1°-30'
	2°-00'	1°-48'	1°-36'	1°-36'	1°-48'	1°-48'
	2°-18'	2°-00'	1°-54'	1°-54'	2°-00'	2°-00'
	2°-18'	2°-12'	2°-00'	2°-00'	2°-12'	2°-08'
	2°-30'	2°-18'	2°-04'	2°-04'	2°-12'	2°-12'
	2°-36'	2°-24'	2°-12'	2°-12'	2°-18'	2°-14'
	2°-26'	2°-27'	2°-12'	2°-18'	2°-24'	2°-20'
	2°-00'	2°-24'	2°-04'	2°-12'	2°-14'	2°-12'
	1°-44'	2°-18'	1°-48'	2°-00'	2°-00'	1°-44'
	1°-38'	1°-42'	1°-24'	1°-36'	1°-36'	1°-30'
	1°-12'	1°-24'	1°-10'	1°-24'	1°-24'	1°-14'
	1°-00'	1°-12'	0°-56'	1°-04'	1°-10'	1°-00'
Mean Dec.	1.8095	1.7802	1.5444	1.6191	1.6667	1.6302
SD - Dec.	0.4474	0.4266	0.4064	0.4005	0.4286	0.4194
SD - Deg.	0°-27'	0°-26'	0°-24'	0°-24'	0°-26'	0°-25'
Mean Deg.	1°-49'	1°-47'	1°-33'	1°-37'	1°-40'	1°-38'

Average = 1.648° or 1° 39'
Standard Deviation of Averages = 0.086° or 0° 05' 10"

Note:
BWB is the outside westbound lane.

200-foot (61m) length and these values are shown in Table IV. The check for significant day-to-day variation was obtained by using the statistical "t Test". The "t Test" calculations are also shown in Table IV. The results of this study indicated no significant day-to-day variation in three of the four test sections at a 95 percent probability level. The "t Test" indicated significant variation on one test section; however, the difference in mean superelevation values from one day to the following day was 0°17', which is about the same error as that involved in reading the analog chart. Also, in obtaining data from the analog chart, it should be noted that the beginning and ending points of a test section are marked on the chart with the chart segment then divided into twenty equal parts. If some error is involved in marking the beginning or ending points in the field (visual observations from a vehicle moving at 40 mph (64 km/h)) mismatch occurs in the position of the 21 points on the analog chart. This mismatch causes erroneous superelevation values to be obtained on the measurement spots of one day as compared to the next day. The results of the "t Test" are heavily dependent on the variation between spots which could be due to the mismatch. It is believed these tests indicate no significant day-to-day variation. A one day variation period, October 1 to October 2, which is a short period to test for time variation, was available for this test. However, if the equipment is properly calibrated, the user should not be concerned with equipment variation due to time passage.

Variation Due to Tire Pressure

To determine if tire pressure caused variation in dynamic transverse slope measurements, tests were obtained with two different tire pressures at 40 mph (64 km/h) on two test sections. The two tire pressures were 24 psi (165 kPa) and 31 psi (214 kPa). Also, an additional test was made at the higher tire pressure. Table V shows the results of the tests. The check for significant variation due to tire pressure was accomplished similar to that of day-to-day variation explained above. In each "t Test" no significant variation was found at the 95 percent probability level.

Variation Due to Speed

The checks for variation due to velocity changes were accomplished in the same manner as that explained in the day-to-day and tire pressure variation studies. The results are found in Table VI. Four test sections were used and tire pressure was held constant at 24 psi (165 kPa). Three velocities were used and the statistical tests were conducted between the three pairs of velocities (that is: low vs. medium, low vs. high, and medium vs. high). In two of the four test sections significant variation was found between velocities.

It is believed that variations in speed cause significant changes in the dynamic cross slope values. These variations are probably due to centrifugal force affecting the graviation stabilization of the gyroscope. That is, vertical (or horizontal) reference is changed by the centrifugal

TABLE IV
DYNAMIC SLOPE DEVICE
DAY-TO-DAY VARIATION

Sect. 1 40 mph - 24 psi (64 km/h) (165 kPa)

Date	1WB Oct. 1	1WB Oct. 2	1EB Oct. 1	1EB Oct. 2
1	1°-50'	1°-32'	2°-33'	2°-30'
2	1°-48'	1°-28'	2°-36'	2°-32'
3	1°-45'	1°-26'	2°-42'	2°-36'
4	1°-42'	1°-24'	2°-48'	2°-42'
5	1°-30'	1°-12'	2°-57'	2°-54'
6	1°-24'	1°-02'	3°-06'	3°-00'
7	1°-12'	0°-58'	3°-18'	3°-12'
8	1°-12'	1°-04'	3°-33'	3°-24'
9	1°-21'	1°-12'	3°-39'	3°-36'
10	1°-30'	1°-24'	3°-48'	3°-46'
11	1°-48'	1°-42'	3°-48'	3°-42'
12	2°-00'	1°-52'	3°-42'	3°-36'
13	2°-12'	1°-58'	3°-30'	3°-24'
14	2°-18'	2°-02'	3°-18'	3°-12'
15	2°-24'	2°-10'	3°-06'	3°-04'
16	2°-27'	2°-10'	2°-57'	2°-48'
17	2°-24'	2°-02'	2°-37'	2°-34'
18	2°-18'	1°-36'	2°-27'	2°-26'
19	1°-42'	1°-24'	2°-22'	2°-22'
20	1°-24'	1°-10'	2°-21'	2°-20'
21	1°-12'	0°-50'	2°-15'	2°-14'
Mean Dec.	1.7802°	1.5064°	3.0183°	2.9476°
SD Dec.	0.4266°	0.4075°	0.5134°	0.4927°
SD Deg.	0°-26'	0°-24'	0° 31'	0° 30'
Mean Deg.	1° 47'	1° 30'	3° 01'	2° 57'

$$S_a^2 = \frac{20(0.4266^2) + 20(0.4075^2)}{40}$$

$$S_a^2 = \frac{3.6398 + 3.3211}{40} = 0.1740$$

$$S_a = 0.4172 \sqrt{1/21 + 1/21} = 0.30861$$

$$t = \frac{1.7802 - 1.5064}{(0.4172)(0.30861)} = 2.1266 > 1.684$$

Signif. day-to-day Variat. @95%

$$S_a^2 = \frac{20(0.5134^2) + 20(0.4927^2)}{40}$$

$$S_a^2 = 0.25317$$

$$S_a = 0.50316 \sqrt{1/21 + 1/21} = 0.30861$$

$$t = \frac{3.0183 - 2.9476}{(0.50316)(0.30861)} = 0.455 < 1.684$$

No Signif. day-to-day Variat. @95%

TABLE IV
DYNAMIC SLOPE DEVICE
DAY-TO-DAY VARIATION

Sect 6 — 40 mph - 24 psi (64 km/h) (165 kPa)

	6NB Oct. 1	6NB Oct. 2	6SB Oct. 1	6SB Oct. 2
	2°-10'	2°-06'	2°-00'	2°-02'
	2°-06'	2°-04'	2°-10'	2°-12'
	2°-10'	2°-04'	2°-12'	2°-18'
	2°-10'	2°-04'	2°-24'	2°-20'
	2°-04'	2°-00'	2°-30'	2°-24'
	1°-56'	1°-54'	2°-30'	2°-30'
	1°-56'	1°-54'	2°-36'	2°-36'
	2°-00'	2°-00'	2°-42'	2°-30'
	2°-04'	2°-00'	2°-30'	2°-18'
	2°-10'	2°-08'	2°-24'	2°-12'
	2°-06'	2°-12'	2°-18'	2°-06'
	2°-24'	2°-18'	2°-10'	1°-58'
	2°-32'	2°-28'	2°-00'	1°-48'
	2°-34'	2°-30'	1°-54'	1°-48'
	2°-36'	2°-30'	1°-54'	1°-48'
	2°-36'	2°-30'	1°-54'	1°-48'
	2°-24'	2°-18'	1°-54'	1°-48'
	2°-12'	2°-06'	1°-54'	1°-48'
	2°-06'	2°-00'	1°-54'	1°-48'
	2°-06'	1°-54'	2°-00'	1°-48'
	2°-00'	1°-52'	2°-02'	1°-54'
Mean Dec.	2.1127°	2.1365°	2.1698°	2.0825°
SD Dec.	0.4960°	0.2116°	0.2481°	0.2820°
SD Deg.	0° 30"	0° 13'	0° 15'	0° 17'
Mean De.	2° 07'	2° 08'	2° 10'	2° 05'

(2°-08')-(2°-07') = 0°-01'

$$S_a^2 = \frac{20(0.4960^2) + 20(0.2116^2)}{40}$$

$S_a^2 = 0.1454$ $\quad S_a = 0.3813$

$\sqrt{1/21 + 1/21} = \sqrt{2/21} = 0.30861$

$$t = \frac{2.1365 - 2.1127}{(0.3813)\ (0.30861)} = 0.202 < 1.684$$

No Signif. day-to-day Variat. @95%

(2°-10')-(2°-05') = 0°-05'

$$S_a^2 = \frac{20(0.0615) + 20(0.07952)}{40}$$

$S_a^2 = 0.07054$ $\quad S_a = 0.26559$

$\sqrt{2/21} = 0.30861$

$$t = \frac{2.1698 - 2.0825}{(0.30861)(0.26559)} = \frac{0.08730}{0.08196} = 1.065 < 1.684$$

No Signif. day-to-day Variat. @95%

40 mph
(64 km/h)

TABLE V
DYNAMIC SLOPE DEVICE
VARIATION DUE TO TIRE PRESSURE
SECTION NO 1-EB

Spot No	24 psi (165 kPa) Run #1	Run #2	Run #3	31 psi (214 kPa) Run #1	Run #2	Run #3
1	2°-30'			2°-42'	2°-40'	
2	2°-32'			2°-48'	2°-46'	
3	2°-36'			2°-48'	2°-48'	
4	2°-42'			2°-58'	2°-50'	
5	2°-54'			3°-08'	3°-02'	
6	3°-00'			3°-14'	3°-12'	
7	3°-12'			3°-30'	3°-24'	
8	3°-24'			3°-38'	3°-36'	
9	3°-36'			3°-48'	3°-44'	
10	3°-46'			3°-50'	3°-48'	
11	3°-42'			3°-50'	3°-48'	
12	3°-36'			3°-48'	3°-44'	
13	3°-24'			3°-36'	3°-36'	
14	3°-12'			3°-22'	3°-20'	
15	3°-04'			3°-14'	3°-12'	
16	2°-48'			2°-56'	2°-56'	
17	2°-34'			2°-44'	2°-44'	
18	2°-26'			2°-36'	2°-34'	
19	2°-22'			2°-34'	2°-26'	
20	2°-20'			2°-30'	2°-26'	
21	2°-14'			2°-24'	2°-24'	

Mean Dec.	2.9476			3.1413	3.0952°
SD Dec.	.4927			.4861	.4866°
SD Deg.	0° 30'			0° 29'	0° 29'
Mean Deg.	2° 57'			3° 08'	3° 06'

$$S_a^2 = \frac{20(0.4927^2) + 20(0.4861^2)}{40}$$

$S_a^2 = 0.23952$ $\quad S_a = 0.48941$

$\sqrt{1/21 + 1/21} = 0.30861$

$$t = \frac{2.9476 - 3.1413}{(0.48941)(0.30861)} = \frac{0.19370}{0.15104} = 1.282 < 1.684$$

No Signif. Diff.
Due to Tire Press. @95%

$$S_a^2 = \frac{20(0.4927^2) + 20(0.4866^2)}{40}$$

$S_a^2 = 0.23976$ $\quad S_a = 0.48966$

$\sqrt{1/21 + 1/21} = 0.30861$

$$t = \frac{3.0952 - 2.9476}{(0.48966)(0.30861)} = 0.977 < 1.684$$

No Significant Diff.
Due to Tire Press. @95%

40 mph
(64 km/h)

TABLE V
DYNAMIC SLOPE DEVICE
VARIATION DUE TO TIRE PRESSURE
SECTION No. 1-WB

Spot No	24 psi (165 kPa) Run #1	Run #2	Run #3	31 psi (214 kPa) Run #1	Run #2	Run #3
1	1°-32!			1°-36'	1°-36'	
2	1°-28'			1°-30'	1°-32'	
3	1°-26'			1°-24'	1°-30'	
4	1°-24'			1°-18'	1°-24'	
5	1°-12'			1°-12'	1°-18'	
6	1°-02'			1°-02'	1°-06'	
7	0°-58'			0°-56'	1°-00'	
8	1°-04'			1°-02'	1°-06'	
9	1°-12'			1°-14'	1°-14'	
10	1°-24'			1°-26'	1°-24'	
11	1°-42'			1°-40'	1°-36'	
12	1°-52'			1°-48'	1°-54'	
13	1°-58'			2°-00'	2°-02'	
14	2°-02'			2°-06'	2°-06'	
15	2°-10'			2°-10'	2°-10'	
16	2°-10'			2°-10'	2°-12'	
17	2°-02'			2°-00'	2°-06'	
18	1°-36'			1°-36'	1°-48'	
19	1°-24'			1°-18'	1°-28'	
20	1°-10'			1°-04'	1°-18'	
21	0°-50'			0°-48'	1°-00'	

	24 psi Run #1	31 psi Run #1	31 psi Run #2
Mean Dec.	1.50635°	1.49206°	1.56349°
SD Dec.	0.40752°	0.42281°	0.39481°
SD Deg.	0° 24'	0° 25'	0° 24'
Mean Deg.	1° 30'	1° 30'	1° 34'

$$S_a^2 = \frac{20(0.4075) + 20(0.42281)}{40}$$

$S_a^2 = 0.17342$ $S_a = 0.41524$

$\sqrt{1/21 + 1/21} = 0.30861$

$$t = \frac{1.50635 - 1.49206}{0.12815} = 0.112 < 1.684$$

No Sign. Diff.
Due To Tire Pressure @95%

$$S_a^2 = \frac{20(0.40752) + 20(0.39481)}{40}$$

$S_a^2 = 0.16097$ $S_a = 0.40122$

$\sqrt{1/21 + 1/21} = 0.30861$

$$t = \frac{1.56349 - 1.50635}{0.12382} = 0.461 < 1.684$$

No Sign. Diff.
Due To Tire Pressure @95%

TABLE VI
DYNAMIC SLOPE DEVICE
VARIATION DUE TO SPEED
SECTION No. 1-EB

24 psi
(165 kPa)

Spot No.	20 mph (32 km/h)	40 mph (64 km/h)	60 mph (97 km/h)
1	2°-54'	2°-30'	2°-18'
2	2°-54'	2°-32'	2°-18'
3	3°-00'	2°-36'	2°-18'
4	3°-04'	2°-42'	2°-26'
5	3°-12'	2°-54'	2°-30'
6	3°-20'	3°-00'	2°-42'
7	3°-30'	3°-12'	2°-48'
8	3°-42'	3°-24'	3°-04'
9	4°-00'	3°-36'	3°-06'
10	4°-06'	3°-46'	3°-18'
11	4°-14'	3°-42'	3°-18'
12	4°-14'	3°-36'	3°-16'
13	4°-06'	3°-24'	3°-12'
14	3°-54'	3°-12'	3°-04'
15	3°-42'	3°-04'	2°-54'
16	3°-36'	2°-48'	2°-42'
17	3°-18'	2°-34'	2°-36'
18	3°-06'	2°-26'	2°-24'
19	2°-56'	2°-22'	2°-12'
20	2°-56'	2°-20'	2°-00'
21	2°-54'	2°-14'	1°-56'

Mean Dec.	3.45873°	2.94762°	2.68413°
SD DEC.	0.48670°	0.49268°	0.43495°
SD Deg.	0° 29'	0° 30'	0° 26'
Mean Deg.	3° 28'	2° 57'	2° 41'

TABLE VI

20 mph vs 40 mph
(32 km/h) vs 64 km/h)

$$S_a^2 = \frac{20(0.4867^2) + 20(0.49286^2)}{40} = 0.23981$$

$$S_a = 0.4897$$

$$\sqrt{1/21 + 1/21} = 0.30861$$

$$t = \frac{0.51111}{0.15113} = 3.3819 > 1.684$$

Significant Difference in Variation Due to Speed Change from 20 mph (32 km/h) to 40 mph (64 km/h) at 95% Probability Level.

40 mph vs 60 mph
(64 km/h) vs 97 km/h)

$$S_a^2 = \frac{20(0.49268^2) + 20(0.43495^2)}{40} = \frac{4.85467 + 3.78363}{40} = 0.21596$$

$$S_a = 0.46471$$

$$\sqrt{1/21 + 1/21} = 0.30861$$

$$t = \frac{0.06508}{0.14341} = 1.837 > 1.684$$

Significant Difference in Variation Due to Speed Change from 40 mph (64 km/h) to 60 mph (97 km/h) at 95% Probability Level.

20 mph vs 60 mph
(32 km/h) vs 97 km/h)

$$S_a^2 = \frac{20(0.48670^2) + 20(0.43495^2)}{40} = \frac{20(.236877) + 20(.1891815)}{40} = 0.213029$$

$$S_a = 0.461551$$

$$\sqrt{1/21 + 1/21} = 0.30861$$

$$t = \frac{0.774600}{0.142439} = 5.438 > 1.684$$

Significant Difference in Variation Due to Speed Change from 40 mph (64 km/h) to 60 mph (97 km/h) at 95% Probability Level.

TABLE VI
DYNAMIC SLOPE DEVICE
VARIATION DUE TO SPEED
SECTION No. 1-WB

24 psi
(165 kPa)

SPOT	20 mph (32 km/h)			40 mph (64 km/h)			60 mph (97 km/h)		
No.	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
1	1°-36'			1°-32'			1°-30'		
2	1°-36'			1°-28'			1°-26'		
3	1°-34'			1°-26'			1°-20'		
4	1°-24'			1°-24'			1°-12'		
5	1°-18'			1°-12'			1°-02'		
6	1°-12'			1°-02'			1°-02'		
7	0°-58'			0°-58'			1°-06'		
8	1°-00'			1°-04'			1°-14'		
9	1°-12'			1°-12'			1°-24'		
10	1°-18'			1°-24'			1°-36'		
11	1°-42'			1°-42'			1°-54'		
12	1°-54'			1°-52'			2°-04'		
13	2°-00'			1°-58'			2°-10'		
14	2°-06'			2°-02'			2°-12'		
15	2°-06'			2°-10'			2°-18'		
16	1°-52'			2°-10'			2°-18'		
17	1°-30'			2°-02'			2°-12'		
18	1°-12'			1°-36'			1°-52'		
19	0°-54'			1°-24'			1°-36'		
20	0°-40'			1°-10'			1°-24'		
Mean Dec.	1.4533°			1.5400°			1.6433°		
SD Dec.	0.4126°			0.3870°			0.4436°		
SD Deg.	0° 25'			0° 23'			0° 27'		
Mean Dec.	1° 27'			1° 32'			1° 39'		

TABLE VI
VARIATION DUE TO SPEED
SECTION No. 1-WB

20 mph vs 40 mph
(32 Km/h) vs 64 km/h)

$$S_a^2 = \frac{19(0.4126^2) + 19(0.3870^2)}{38} = \frac{3.23454 + 2.84561}{38} = 0.1600$$

$$S_a = 0.4000$$

$$\sqrt{1/20 + 1/20} = 0.31623$$

$$t = \frac{0.08670}{0.12649} = 0.6854 < 1.684$$

No Significant Difference in Variation Due to Speed Change from 20 mph (32 km/h) to 40 mph (64 km/h) at the 95% Probability Level.

40 mph vs 60 mph
(64 km/h) vs 97 km/h)

$$S_a^2 = \frac{19(0.3870^2) + 19(0.4436^2)}{38} = \frac{2.84561 + 3.73884}{38} = 0.17327$$

$$S_a = 0.41626$$

$$\sqrt{1/20 + 1/20} = 0.31623$$

$$t = \frac{0.10330}{0.13163} = 0.785 < 1.684$$

No Significant Difference in Variation Due to Speed Change from 40 mph (64 km/h) to 60 mph (97 km/h) at the 95% Probability Level.

20 mph vs 60 mph
(32 km/h) vs 97 km/h)

$$S_a^2 = \frac{19(0.4126^2) + 19(0.4436^2)}{38} = \frac{3.23454 + 3.73884}{38} = 0.18351$$

$$S_a = 0.42838$$

$$\sqrt{1/20 + 1/20} = 0.31623$$

$$t = \frac{0.1900}{0.13547} = 1.403 < 1.684$$

No Significant Difference in Variation Due to Speed Change from 20 mph (32 km/h) to 60 mph (97 km/h) at the 95% Probability Level.

TABLE VI
DYNAMIC SLOPE DEVICE
VARIATION DUE TO SPEED
SECTION No. 6-SB

24 psi
(165 kPa)

SPOT No.	20 mph (32 km/h) Run 1	Run 2	Run 3	40 mph (64 km/h) Run 1	Run 2	Run 3	60 mph (97 km/h) Run 1	Run 2	Run 3
1	2°-06'						2°-14'		
2	2°-18'			2°-02'			2°-22'		
3	2°-24'			2°-12'			2°-26'		
4	2°-34'			2°-18'			2°-36'		
5	2°-36'			2°-20'			2°-36'		
6	2°-38'			2°-24'			2°-36'		
7	2°-42'			2°-30'			2°-42'		
8	2°-48'			2°-36'			2°-46'		
9	2°-42'			2°-30'			2°-42'		
10	2°-30'			2°-18'			2°-36'		
11	2°-24'			2°-12'			2°-28'		
12	2°-18'			2°-06'			2°-24'		
13	2°-08'			1°-58'			2°-24'		
14	2°-00'			1°-48'			2°-12'		
15	2°-00'			1°-48'			2°-08'		
16	2°-04'			1°-48'			2°-02'		
17	2°-02'			1°-48'			2°-00'		
18	2°-10'			1°-48'			2°-00'		
19	2°-02'			1°-48'			2°-02'		
20	2°-06'			1°-48'			2°-04'		
21	2°-10'			1°-54'			2°-04'		

	20 mph	40 mph	60 mph
Mean Dec.	2.3048°	2.0967°	2.3524°
SD Dec.	0.2522°	0.2816°	0.2630°
SD Deg.	0° 15'	0° 17'	0° 16'
Mean Deg.	2° 18'	2° 06'	2° 21'

TABLE VI
VARIATION DUE TO SPEED
SECTION No. 6-SB

20 mph vs 40 mph
(32 km/h) vs 64 km/h)

$$S_a^2 = \frac{20(0.2522^2) + 19(0.2816^2)}{39} = \frac{1.27210 + 1.50667}{39} = 0.07125$$

$$S_a = 0.26693$$

$$\sqrt{1/21 + 1/20} = 0.31244$$

$$t = \frac{0.20810}{0.08340} = 2.495 > 1.684$$

Significant Difference in Variation Due to Speed Change from 20 mph (32 km/h) to 40 mph (64 km/h) @95% Probability Level.

40 mph vs 60 mph
(64 km/h) vs 97 km/h)

$$S_a^2 = \frac{19(0.2816^2) + 20(0.2630^2)}{39} = \frac{1.50667 + 1.38338}{39} = 0.0741$$

$$S_a = 0.27222$$

$$\sqrt{1/21 + 1/20} = 0.31244$$

$$t = \frac{0.25570}{0.08505} = 3.006 > 1.684$$

Significant Difference in Variation Due to Sped Change from 40 mph (64 km/h) to 60 mph (97 km/h) @95% Probability Level.

20 mph vs 60 mph
(32 km/h) vs 97 km/h)

$$S_a^2 = \frac{20(0.2522^2) + 20(0.2630^2)}{40} = \frac{1.27210 + 1.38338}{40} = 0.06639$$

$$S_a = 0.25766$$

$$\sqrt{1/21 + 1/21} = \sqrt{2/21} = 0.30861$$

$$t = \frac{0.04760}{0.07952} = 0.599 < 1.684$$

No Significant Difference in Variation Due to Speed Change from 20 mph (32 km/h) to 60 mph (97 km/h) @95% Probability Level.

TABLE VI
DYNAMIC SLOPE DEVICE
VARIATION DUE TO SPEED
SECTION No. 6-NB

24 psi
(165 kPa)

SPOT	20 mph (32 km/h)			40 mph (64 km/h)			60 mph (97 km/h)		
No.	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
1	2°-04'			2°-06'			2°-02'		
2	2°-02'			2°-04'			2°-00'		
3	1°-58'			2°-04'			2°-04'		
4	1°-54'			2°-04'			2°-04'		
5	1°-54'			2°-00'			2°-04'		
6	1°-54'			1°-54'			1°-56'		
7	1°-48'			1°-54'			1°-54'		
8	1°-50'			2°-00'			1°-56'		
9	1°-54'			2°-00'			2°-00'		
10	1°-54'			2°-08'			2°-02'		
11	2°-00'			2°-12'			2°-06'		
12	2°-06'			2°-18'			2°-06'		
13	2°-14'			2°-28'			2°-14'		
14	2°-24'			2°-30'			2°-18'		
15	2°-26'			2°-30'			2°-26'		
16	2°-26'			2°-30'			2°-26'		
17	2°-18'			2°-18'			2°-30'		
18	2°-06'			2°-06'			2°-30'		
19	2°-00'			2°-00'			2°-20'		
20	1°-58'			1°-54'			2°-14'		
21	1°-54'			1°-52'			2°-08'		

	20 mph (32 km/h)	40 mph (64 km/h)	60 mph (97 km/h)
Mean Dec.	2.0508°	2.1365°	2.1587°
SD Dec.	0.1977°	0.2116°	0.1909°
SD Deg.	0° 12'	0° 13'	0° 11'
Mean Deg.	2° 03'	2° 08'	2° 10'

TABLE VI
VARIATION DUE TO SPEED
SECTION No. 6-NB

20 mph vs 40 mph
(32 km/h) vs 64 km/h)

$$S_a^2 = \frac{20(0.1977^2) + 20(0.2116^2)}{40} = \frac{0.78171 + 0.89549}{40} = 0.04193$$

$S_a = 0.20477$

$\sqrt{1/21 + 1/21} = 0.30861$

$t = \frac{0.08570}{0.06319} = 1.356 < 1.684$

No Significant Difference in Variation Due to Speed Change from 20 mph (32 km/h) to 40 mph (64 km/h) @95% Probability Level.

40 mph vs 60 mph
(64 km/h) vs 97 km/h)

$$S_a^2 = \frac{20(0.2116^2) + 20(0.1909^2)}{40} = \frac{0.89549 + 0.72886}{40} = 0.04061$$

$S_a = 0.20152$

$\sqrt{1/21 + 1/21} = 0.30861$

$t = \frac{0.02220}{0.06219} = 0.357 < 1.684$

No Significant Difference in Variation Due to Speed Change from 40 mph (64 km/h) to 60 mph (97 km/h) @95% Probability Level.

20 mph vs 60 mph
(32 km/h) vs 97 km/h)

$$S_a^2 = \frac{20(0.1977^2) + 20(0.1909^2)}{40} = \frac{0.78171 + 0.72886}{40} = 0.03776$$

$S_a = 0.19433$

$\sqrt{1/21 + 1/21} = 0.30861$

$t = \frac{0.10790}{0.05997} = 1.799 > 1.684$

Significant Difference in Variation Due to Speed Change from 20 mph (32 km/h) to 60 mph (97 km/h) @95% Probability Level.

force such that the vertical reference is no longer vertical. Higher speeds and curves with longer lengths would increase the error encountered. It should be noted that in the tests performed, the distances traveled during the testing of any one section were generally less than two miles.

Evaluation Summary

The above studies indicate the repeatability of the equipment is about the same, or within the error of reading the analog trace, which is about 0°12'. The day-to-day variation and the variation due to tire pressure changes are insignificant if the equipment is properly calibrated and the tire pressure is maintained within ± 3 psi (20.6 kPa) (approximately one half the range of 7 psi (48 kPa) or 31-24 psi (214 kPa - 165 kPa). Large speed changes, on the order of 20 mph (32 km/h), during testing should be avoided since the above study indicated significant variation. Therefore, it is suggested that tests be conducted at 40 mph (64 km/h) ± 5 mph (8 km/h). Even though tire pressure changes seem insignificant, 24 psi ± 2 psi (165 kPa ± 13.7 kPa) is suggested. Before obtaining test on any given curve the gyroscope should be stabilized by parking the equipment on the shoulder for approximately one minute. The strip chart recorder shows a slight movement when initially stopped, then becomes constant within one minute. The length from the position where stopped to the end of test should be held to a minimum, preferably less than two miles.

Further testing was accomplished observing the above suggestions.

Relationship Between Mechanical and Dynamic Transverse Slope Measurements

Transverse slope measurements were obtained on each of the test sections shown in Table II. These slope measurements were collected with both the mechanical and dynamic measuring devices as previously described. Appendix A contains the values obtained in this study. Figure 6 is a plot of the values obtained by the two devices. The slope is 1.04 indicating the average values are close to being equivalent. The range of the scatter of data about the linear equation curve is about ± 0°24'.

The studies of the Dynamic Superelevation Measuring Device reveal the device is capable of obtaining accurate transverse slope information. Rather than obtaining continual transverse slope information as initially envisioned, it will be necessary to stop immediately before a test section in order that the gyroscope can stabilize. Lengths to be tested after the stabilization should be less than two miles (3.2 km).

The usefulness of the dynamic device will probably be to measure or inventory the superelevations on large numbers of curves as an operation separate from obtaining skid tests. The measurement of superelevation on small numbers of curves can best be accomplished manually.

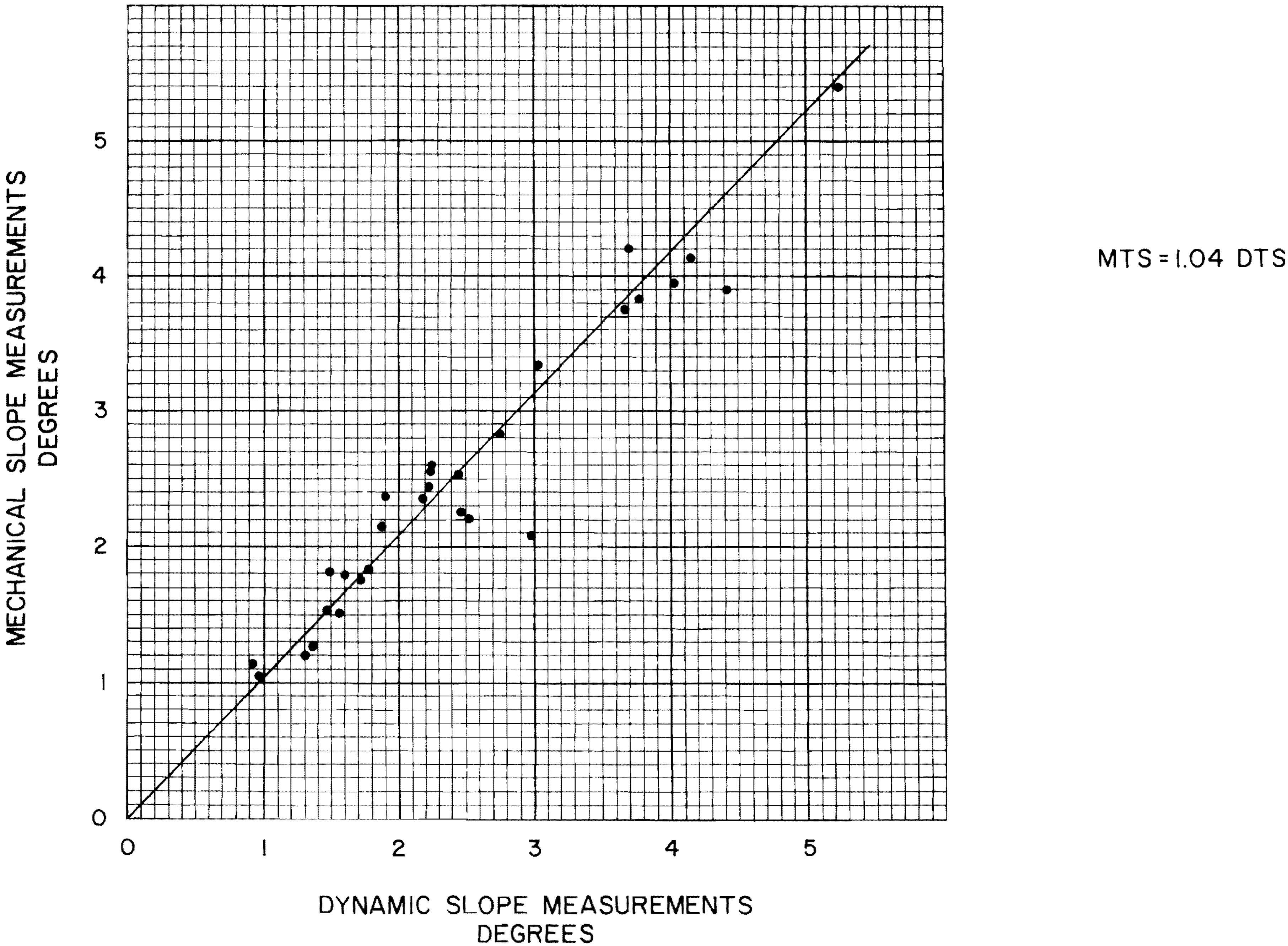


FIGURE 6—PLOT OF MECHANICAL vs. DYNAMIC SLOPE MEASUREMENTS

Comparison of Design and Measured Superelevation Values

Because of the lack of time available in the project after the dynamic equipment was completed, little study was accomplished on transverse slopes existing on Texas highways. However, in an attempt to develop as much information as possible, the design superelevations were obtained for the horizontal curves on which test sections occurred. The design superelevations are shown in Table II. The same design superelevations may be found in Table VII where a comparison was made with the present dynamically measured superelevations. The "Low Side" and "High Side" found in Table VII refer to relative elevations. Actually "Low Side" refers to the lane(s) closer to the centerpoint of the horizontal curve where as the "High Side" is the lane(s) further from the centerpoint. The data in Table VI indicate some 38 percent of the test sections have superelevation values less than the original design.

It may be noted from the data in Table VII the "High Side" of a horizontal curve generally has less superelevation as compared to the "Low Side". Also, the "High Side" generally has less superelevation than specified in the original design. The "Low Side" generally conforms or has slightly greater superelevation as compared to the original design.

As the Engineer of Highway Safety suggested at the initiation of this phase of the study, volumetric changes in the subgrade and errors in construction or overlay practices are evident in the data collected.

With the exception of multilane highways a parabolic crown is usually set on an asphaltic concrete laydown machine. The parabolic crown should be changed through a horizontal curve to conform to a linear transverse slope. If the parabolic crown setting is not changed, less mat thickness could occur near the outside of the lane as compared to the mid or quarter point of the lane. An overlay which was placed with less mat thickness toward the outside of the lane would explain greater superelevations on the "Low Side" and less superelevations on the "High Side".

Also in the initial construction there would probably be a tendency for an operator to round the transverse slope while blading the base in horizontal curves. Even though elevation stakes are set, this type of construction is possible with inexperienced maintainer operators and could cause the effect noted.

The analog chart in Figure 2 is typical of the data collected in this study. Generally, a continuous analog trace through a given curve indicates variation in the superelevation values similar to those shown in Figure 2. Since the measurements were obtained in the center of the horizontal curves, little effect due to transition (from cross slope to superelevation) should be noted. The variation shown in the traces could be due to a variety of items, including volumetric change in the subgrade.

Regardless of the reason for superelevations which are different from design, insufficient or rapidly changing superelevations can be dangerous to vehicular traffic.

TABLE VII
COMPARISON
OF
DESIGN AND
MEASURED SUPERELEVATIONS

DESIGN	MEASURED	
	Low Side	High Side
0.05 ft/ft *	0.06 ft/ft *	0.03 ft/ft *
0.04	0.03	0.02
0.05	0.05	0.02
0.08	0.08	0.03
0.08	0.09	0.07
0.04	0.04	0.04
0.04	0.03	0.04
0.02	0.04	0.02
0.04	0.07	0.05
0.05	0.07	0.04
0.04	-	0.04

*To convert to cm/m
move decimal 2 places
to the right

IV. An Asphaltic Concrete Mix Design Technique for Predetermining Skid Resistance

Probably the most advanced method of measuring and reporting pavement surface texture has been reported by Schonfeld.[2] Schonfeld reported six parameters which when combined would indicate the pavement texture. These parameters are as follows:

Parameter Name	Description
A	Macrotexture Height.
B	Macrotexture Width.
C	Macrotexture Shape.
D	Density of Macrotexture in the Surface.
E	Microtexture Height on Macrotexture Particles.
F	Microtexture Height of Background or Matrix.

The profiles in Tables VIII through XIII in Appendix D provide additional descriptions of the parameters. Schonfeld at one time had a seventh variable denoting small background holes which was associated with the surface water holding capacity. It is believed that this seventh variable was deleted by Schonfeld as unnecessary or insignificant as compared to the other six. Later, in personal correspondence, Schonfeld suggested that the C and E parameters be combined since the two parameters were closely associated. The lower portion of table VIII reflects the suggested combination.

After several years of close observations and study of pavement texture, it was apparent that the parameters used by Schonfeld described the skid resistant properties of the pavement surface in an excellent manner.[3][4][5][6][7][8][9][10] A large portion of the skid resistance developed by a given tire at the tire-pavement contact zone stems from the microtexture. Of course that microtexture in more intimate contact with the tire is more important than that which is not. Therefore, the microtexture on the macrotexture particles (Parameter E) is more important than the background microtexture (Parameter F) unless there is little or widely spaced macrotexture. Macrotexture also contributes to the skid resistance. The greater the ratio of height (Parameter A) to width (Parameter B) the greater the skid resistance. Also the greater the width (Parameter B) the greater the influence of microtexture on the macrotexture particles (Parameter E). The density of the macrotexture (Parameter D) explains the amount of macrotexture available on a given surface (Parameters A & B), and therefore the amount of microtexture on the macrotexture particles (Parameter E) that is available to the tire and the extent that the background microtexture will be available to the tire (Parameter F). The shape of the macrotexture is an elusive variable which is very difficult to quantify. Tests with the British Portable Tester on British Wheel specimens indicate the sharp angular edges on the aggregate particles produce British Portable Numbers that are almost as large as those produced by aggregate particles with good or large microtexture. It is natural that macrotexture shape (Parameter C) be combined with Parameter E to explain the surface condition of the macrotexture. The parameters and charts reported by Schonfeld, ofcourse, include and quantify the items explained above.

There is also a natural tendency to associate the parameters to pavement surfaces. For example, a surface with only Parameter F reported is quickly associated either with a new gritty, sand asphaltic mixture if large F Parameter values are noted, or with a highly flushed surface if low or small F Parameter values are noted. If the D Parameter is 3, or around 75% of the surface is macrotexture, and if large A Parameters are found, a penetration or chip seal is visualized. Schonfeld also encourages the pavement designer to study local materials with the idea of predicting values of the texture parameters based on the materials' characteristics. Basically, these concepts and the association of texture parameters with known existing surfaces led to the envisioning of an asphaltic design concept for skid resistance.

Concepts of the Mix Design Technique

It is possible to assign values for the texture parameters based on test data and then use the charts reported by Schonfeld to predict the skid resistance. In order to predict terminal skid resistance, the values assigned to the texture parameters must be those for a terminal condition.

In studying pavements of weathered or trafficked asphaltic concrete surfaces, it is apparent that the coarse aggregate particles of the mix form the macrotexture. The background microtexture results from the fine aggregate particles of the mix. In Texas the 10 mesh sieve is considered the break point between coarse and fine aggregate, with +10 mesh being the coarse aggregate. Work with aggregate blends in asphaltic concrete mixes using a circular track led to the following conclusion:[5]

> "Laboratory tests indicate a linear (percentage) relationship between the friction properties of aggregates when they are blended in volumetric percentages, including the fine aggregate."

The conclusion also urged caution in relating laboratory-based results with response obtained in the field; however, the conclusion, stated differently, would indicate the volumetric percentage of the various types of materials is also found in the surface area in the same percentage. This means that the amount of coarse aggregate in the mix expressed as a volumetric percentage can also be used to express the percent of the surface area covered by coarse aggregate and to state a density (Parameter D) value.

The Construction Division has made available to the Districts' field personnel "Construction Bulletin, C-14" which shows an asphaltic concrete mix design procedure.[11] This procedure is followed by most Departmental personnel responsible for mix designs. The procedure used in developing an asphaltic concrete mix technique for predetermining skid resistance was to combine the procedure used in the C-14 bulletin with the information reported by Schonfeld. The technique involves using the gradations of the aggregate, established by sieve analysis to obtain a weighted average size of the +10 mesh portion and a -10 mesh portion of the mix. This size is used as a measure of the A, B and F parameters. The volumetric percentage of the +10 mesh portion of the mix is used as a measure of the D parameter. The British Wheel Polish Value is used as a measure of the E + C parameter.

In order to develop this technique it was necessary to establish certain items of information based on judgement. It was believed that these items could be verified and/or changed by comparing the SN values predicted by the technique with SN values obtained in the field. The items which were arbitrarily established are as follows:

1. The Polish Values obtained with the British Wheel test range from the low 20's to the low 50's. It was assumed that Schonfeld's E + C texture parameter would have a linear relationship with the Polish Value. The resulting relationship is found in Table VIII of Appendix D.

2. As stated previously the A parameter or macrotexture height is assumed to be a function of the weighted average size of the +10 mesh portion of the aggregate of the mix. However, it was assumed that once the aggregate was integrated into the total mix and aged (weathered, trafficked, etc.) only 25 percent of its size would be available as macrotexture height. Further, it was assumed that minute particle attrition would occur on the coarse aggregate reducing the effective macrotexture height. This attrition was assumed to be a function of Average Daily Traffic (ADT) and Los Angeles Abrasion values (L.A. Abrasion). That is, large L.A. wear losses would be associated with larger attrition losses. However, greater attrition could be expected where highway surfaces had longer periods between traffic passes to weather.

   It was believed that in no case would attrition be greater than 35 percent of the available macrotexture height. Table IX of Appendix D indicates the recommended adjustment factor for attrition loss. Table X in Appendix D contains Parameter A values recommended by Schonfeld. Form 3 in Appendix E is the calculation sheet.

3. The B Parameter or macrotexture width was assumed to be 75 percent of the weighted average size of the +10 portion of the mix. The 75 percent value was derived through a graphical solution assuming a spherical aggregate. Form 3 of Appendix E is the calculation sheet and Table XI in Appendix D contains Parameter B values recommended by Schonfeld.

4. As stated previously, the D Parameter is obtained from the volumetric gradation information. The percent of the +10 portion of the aggregate is used in conjunction with Table XII of Appendix D. Table XII contains Parameter D values recommended by Schonfeld and Form 1 in Appendix E is the calculation sheet.

Note that Form 544 Rev. (2), Form 1 and Form 2 in Appendix E are used in the calculations. The information on these forms relate to the cold bin analysis at the mix design stage in which the various aggregate materials are combined. Most of the mix design work in Texas deals in weight rather than volume. Therefore, it is somewhat unusual to express gradation percentages by volume. Recently there has been a few Districts (field) which have begun to use a volumetric design procedure. This change has been due to the newer materials (lightweight synthetic aggregates) which have small specific gravities compared to the usual (natural) materials. In any event, most laboratories obtain specific gravities of the materials from the various sources (cold bins) to be used in the mix. The specific gravity is the only additional item needed to convert percentages by weight to percentages by volume. Therefore, there is no additional test cost to perform the suggested design technique for a skid resistance check.

5. The F parameter is obtained from the average weighted size of the -10 mesh portion of the aggregate in the mix. It was assumed that the weathering, microabrasion or polish of the fine aggregate would be reflected by the insoluble residue test. An estimate of the reduction in the height of the background microtexture (Parameter F) may be found in Equation 1 in Appendix D which results in the Fine Aggregate Reduction Factor (FARF). It was assumed the fine aggregate would have very little (actually no) embedment in the asphalt along the surface of the mat. Table XIII in Appendix D indicates the F parameters as suggested by Schonfeld.

The charts numbered 1 through 4 in Appendix D were obtained from Mr. Schonfeld. The charts contain some of the latest revisions reflecting random or a planned transverse (grooving or initial construction finish) texture. For the purposes of the technique reported herein, use of the random texture information is recommended.

At this point it should be noted that the above assumptions are based on the theory that the Skid Numbers to be predicted should be those of the pavement's terminal or "as polished" condition. The Polish Values, embedment of the coarse aggregate, adjustment for coarse aggregate attrition loss, and Fine Aggregate Reduction Factor all reflect a polished or aged surface.

Description of Calculations

The following outline is a detailed description of the calculations necessary for predicting the skid resistance of a proposed mix. Also, two examples are given in Appendix F. Note both examples are Type D mixes found in the Standard Specifications of Texas. One example uses siliceous gravel coarse aggregate whereas a sandstone is used in the other. The description is as follows:

1. Obtain Mix Combination and Gradation Information from "Asphaltic Concrete Sieve Analysis Work Sheet" Form No. 544. Copy this information on Form 1.

2. Complete Form 2 by listing the "Percent by Weight of the Total Mix" for each bin and the asphalt. List the specific gravity of each material. Divide the Percent by Weight (Column a) by the Specific Gravity (Column b) for each material and list in Column c. Sum Column c. Divide each entry in Column c by the Total found for Column c to determine the Percent by Volume of the total mix for each material and list in Column d.

3. Complete the percent by volume columns of Form 1 to determine the percent by volume of each sieve size by multiplying the "% by Weight" with the volume percentage of the bin in question. Sum the "% by Volume" values for each sieve size and record under the "Combined Analysis % by Volume" column in the usual manner. The cumulative sum of the "+10" (+2.00mm) portion is equal to the value "D". Obtain D from Table XII using D%. Record on Form 5.

4. The Values of "A", "B" and "F" may be calculated using a weighted average method found on Form 3. First copy the "Combined Analysis % by Volume" of the "+10" portion from Form 1 onto Form 3. Multiply the "Average Sieve Size in mm" (Column a) by the Combined Analysis (Column b) and record in Column c. Sum Column c and Column b. Divide the sum of Column c by the sum of Column b to determine the Weighted Average Size. The average height of the coarse aggregate protruding from the asphaltic concrete surface is estimated to be 25 percent of the Weighted Average Size and may be calculated as A_u on Form 3. To calculate A_u, multiply 0.25 by c/a.

   Since decay or attrition of the coarse aggregate occurs, the attrition is assumed to be a function of the mechanical abrasion as measured by the L.A. Wear Test. It is further assumed that the attrition caused by tire wear would be more severe if the aggregate is exposed to weathering for longer periods before tire passage. Or, considering a surface has polished to its lowest skid resistance level, those surfaces with less traffic per day would have more chance of weathering than surfaces with higher Average Daily Traffic. Estimates of the combined effect of weather and traffic are found in Table IX. To obtain "A_c", multiply "A_u" by the appropriate "Coarse Aggregate Height Adjustment Factor" found in Table IX. Determine the "A" values from Table X using "A_c" and record on Form 5.

   The value "Bc" may be calculated by multiplying the Weighted Average Size by 0.75, where the width of the coarse aggregate exposed is assumed to be 75 percent of the size of the aggregate. Determine the "B" value from Table XI using "B_c" and record on Form 5.

The calculation of the "Weighted Average Size" of the fine aggregate is similar to that explained for the coarse aggregate. Equation 1 is an adjustment of the fine aggregate height based on the Insoluble Residue Test. The Value "F_c" may be calculated by multiplying the Weighted Average Size of the fine aggregate (-10) portion of the mix by the "Fine Aggregate Reduction Factor". Determine the "F" value from Table XIII using "F_c" and record on Form 5.

5. Values of "E+C" may be calculated by obtaining a Weighted Polish Value on Form 4. In Column a, record the % by Volume +10 mesh material found in Bin 1 on the first line. On the second line, record the Polish Value of Bin 1 if applicable. (If the coarse aggregate material is not of sufficient size to obtain a test or if the +10 mesh portion of the mix is less than 10%, the Polish Value should be left blank and not considered.) Next, multiply the "% by Volume of the +10 mesh" value by the Polish Value and record on the third line (Total). Repeat the above operation for the other Bins. Sum the "Total" values found on the third line and record in Column e. Sum the "% by Volume of +10 mesh" value for each bin found on the first line and record in Column f.

   Divide the value found in Column e by the value found in Column f to determine the Weighted Polish Value. Using Table VIII, determine the "E+C" value corresponding to the Polish Value (Weighted) and record as "E+C". Also, record the "E+C" value on Form 5.

6. The Texture Parameters "A", "B", "D", "E+C", and "F" have previously been recorded on Form 5. Using Chart 1 and considering a 30 mph "Test Speed", select the appropriate curve which depends on the "E" (or actually the "E+C") value calculated. Find on the abscissa or horizontal scale the "D" value which was calculated. Move vertically from the "D" value until the intersection with the appropriate curve is found. Move horizontally and to the left until intersection is made with the ordinate or vertical "Friction Weight" scale. Determine the "Friction Weight" and record on Form 5. Determine the Friction Weight for "E" for 60 mph in the same manner.

   Repeat the above operation to determine the Friction Weights for "F" and for "B" using Charts 2, 3, or 4. Record each on Form 5. Note that the chart selected depends on the "D" parameter. Use the Random Texture Curves since the Transverse Texture Curves are to be used for striated P.C. Concrete finishes. Finally, sum the Friction Weights of "E", "F", and "B" for each speed and record in the "Total Friction Weight" spaces.

A Comparison of the Predicted Skid Resistance with the Actual Skid Trailer Values

In order to validate the mix design technique, the mix designs of several existing pavement surfaces were obtained. These mix designs were revised to the technique proposed herein and the skid resistance predicted. Several District Laboratory Engineers performed these calculations on existing highways in their District. As a comparison, the skid resistance was obtained on these selected highway sections using a skid test trailer conforming to ASTM-E 274. Note that only those highway sections were selected for study in which at least two million vehicle applications per lane had accrued.

Table XIV shows the predicted texture parameters of the sections selected, various design values, the predicted SN_{40} value and the SN_{40} value actually measured with the skid test unit. Note the Predicted SN_{40} is a linear interpolation between the predicted SN_{30} and SN_{60} values. Figure 7 is a plot of the predicted and actual SN_{40} values.

TABLE XIV
COMPARISON OF PREDICTED AND MEASURED
SKID RESISTANCE

Ident. No.	A	B	C E	D	F	CA Size	C.A. Adj. Fact.
14-1	3.4	2.0	2.4	54.8 2	3	5.87	0.98
14-2	3.5	1.8	3.5	67.1 3	3	6.22	0.98
14-3	3.8	1.6	3.2	67.1 3	4.5	7.35	0.98
14-4	3.8	1.6	3.2	62.9 3	4.0	7.30	0.98
14-5	3.5	1.9	2.4	50.5 2	3.0	6.11	0.95
15-1	3.4	1.9	1.9	56.8 2	4	5.9	0.95
15-2	3.3	1.9	2.1	58.4 2	4	6.0	0.89
15-3	3.4	1.9	2.6	53.5 2	4	5.7	0.98
15-4	3.5	1.9	2.6	53.3 2	4	6.1	0.98
15-5	3.6	1.8	1.9	56.7 2	4	6.6	0.95
15-6	3.5	1.8	1.7	58.4 2	4	6.4	0.95
17-2	3.4	2.1	2.2	43.8 2.0	3	6.2	0.90
17-3	2.7	2.8	2.3	13.6 1.0	4	3.5	0.95
17-5	3.3	2.0	2.0	31.5 1	3	5.9	0.89

TABLE XIV
CONTINUED

Ident. No.	FARF	Polish Value	B	F	E	Predicted SN_{40} Value	Measured SN_{40} Value
14-1	0.755	34	23	3	16	40	41
			23	2	10		
14-2	0.771	45	20	1	40	56	57
			20	1	26		
14-3	0.756	42	21	1	36	54	57
			21	1	24		
14-4	0.783	42	21	3	33	53	58
			21	2	22		
14-5	0.710	34	23	3	14	38	38
			23	3	9		
15-1	0.75	29	23	6	10	37	40
			23	4	5		
15-2	0.75	31	23	6	12	39	45
			23	4	7		
15-3	0.93	36	23	6	20	46	50
			23	4	12		
15-4	0.93	36	23	5	20	45	48
			23	3	12		
15-5	0.875	29	23	5	10	35	37
			23	3	4		
15-6	0.95	27	23	5	9	35	38
			23	3	4		
17-2	0.50	33	24	4	13	39	41
			24	3	7		
17-3	0.50	32	15	13	3	30	37
			15	9	2		
17-5	0.50	30	20	6	6	30	30
			20	3	3		

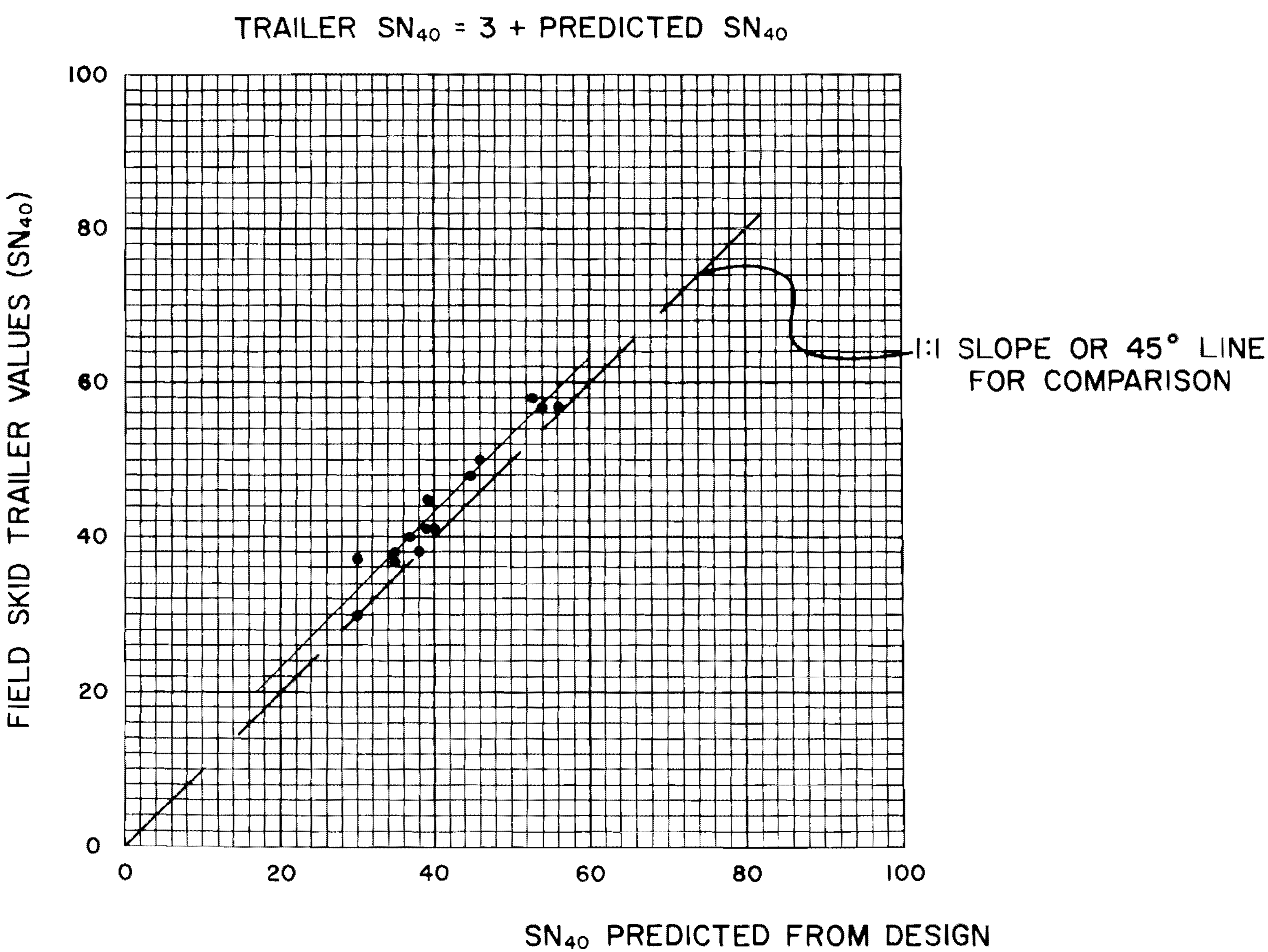


FIGURE 7—COMPARISON OF PREDICTED AND MEASURED SN_{40} VALUES

Figure 7 shows a close relationship with an overall scatter of plot points of 3 to 4 SN_{40} values. The relationship (curve slope) appears to be 1:1, however, it would be necessary to add approximately 3 to the predicted value to determine the trailer measured value.

As stated previously, in order to obtain the best possible relationship between the predicted and the measured skid numbers, it would be possible to change or modify the values of items which were arbitrarily established. The values assigned to the Coarse Aggregate Height Adjustment Factor, Fine Aggregate Reduction Factor, the height percentage (which was orignially set at 25%) and the E + C values assigned to the Polish Value were modified and studied in an effort to improve the relationship shown in Figure 7.

The best relationship between the predicted and measured skid numbers was obtained by changing the Polish Values in the E + C Table to those shown in Table XV. By comparing Table VIII in Appendix D with Table XV it may be noted the Polish Values have been decreased for each E + C value. However, this action in reality has increased the effect of the E + C value about 8%. This 8% increase in E + C values produced the relationship between predicted and measured Skid Numbers shown in Figure 8. Therefore, it is suggested Table XV be substituted for Table VIII. Other than this change the Tables, Charts and Forms should be used as previously described.

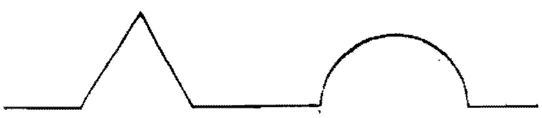
TABLE XV

REVISED
PREDICTION OF THE "E + C" TEXTURE VALUES

E+C TEXTURE VALUE	POLISH VALUE
E 5	56
E 4	46
E 3	37
E 2	28
E 1	19

1

Polished (No Texture Visible)

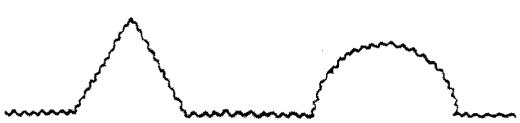


2

Smooth (Texture Visible But Micro — Projections Too Small For Visual Estimate Of Height

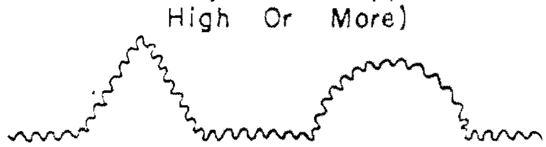
3

Fine Grained (Micro – Projections Appr. 1/4 mm High)



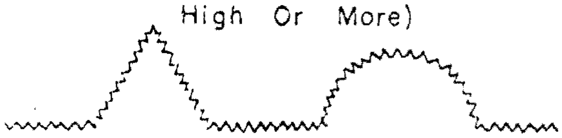
4

Coarse Grained – Subangular (Micro – Projections Appr. 1/2 mm High Or More)



5

Coarse Grained — Angular (Micro – Projections Appr. 1/2 mm High Or More)



CORRECTED "E+C" VARIABLE
BY DECREASING POLISH VALUE
VALUE 8%

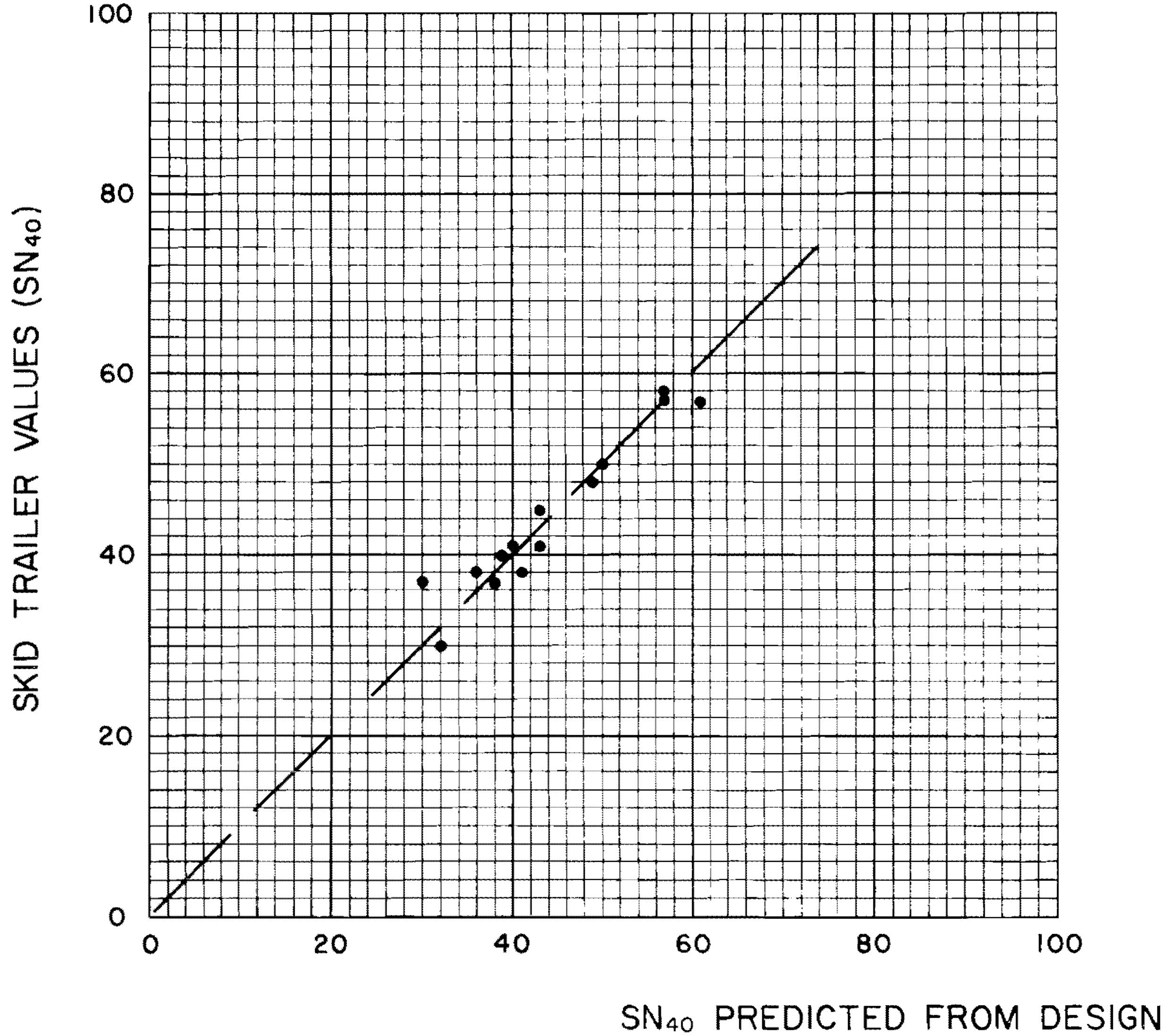


FIGURE 8—COMPARISON OF SKID NUMBERS AFTER MODIFICATION OF E+C VALUES

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11. <u>Construction Bulletin C-14</u>; Construction Division, Texas Highway Department; September, 1964.

APPENDIX A

CALIBRATION OF DYNAMIC CROSS SLOPE DEVICE

CROSS SLOPE DEVICE CALIBRATION

The dynamic cross slope device is set up to read 5 millimetres per degree from the level horizontal plane. Each millimeter between the 1/2 centimeter marks is equal to 12 minutes.

A curve slope to the right will cause the strip chart recorder pen to move to the right, and a curve or elevation slope to the left will cause the recorder pen to move to the left.

If a cross slope is encountered which exceeds the maximum 5 degree limit of the recorder, the "ZERO" may be shifted from the center position to allow for the extra swing to record the increased slope. In this case, the amount of shift or the distance to the new zero position should be recorded (preferably on the chart).

At the Texas Transportation Institute the initial calibration of the trailer was established on a level floor by placing an inclinometer on the trailer axle, lifting the axle with a jack, and checking the strip chart recorder each degree until it reached 5 degrees. This was done in both directions, i.e. the jack was placed under the left wheel for a full calibration and then under the right wheel for a full calibration.

The system is calibrated to have an output, at jack J-2 on the side of the gray cabinet on the trailer, of 0.6 volts DC per degree of incline where 1 Deg. = 0.6 volts, 2 Deg. = 1.2 volts, 3 Deg. = 1.8 volts, 4 Deg. = 2.4 volts, and 5 Deg. = 3.0 volts etc., and of course 0 Deg. = 0 volts. The voltage of course would be either positive or negative depending on the direction of the incline.

The Department's method of calibration will be a simple one. A carpenter's level should be placed on the axle or the trailer should be positioned on a floor which is known to be level. This procedure will be termed the basic calibration ZERO REFERENCE.

After ZERO REFERENCE has been established and the recorder has been zeroed (centered in the middle of the chart paper), the trailer may be lifted by the built-in jacks on the trailer, and a 4X4 block placed under one wheel and the trailer lowered onto the block. The recorder should read 3 Degrees and 12 minutes for a 3-5/8" (92mm) block. This procedure should be used on each wheel, and care should be taken that when the trailer is returned to the ZERO REFERENCE, the recorder returns to ZERO.

The field equipment should contain a carpenter's level for use in case the recorder Zero control is accidentally moved or if the Zero setting is in doubt.

OPERATION AND CALIBRATION CHECK LIST. TRAILER AXLE LEVEL

1.--Activate the "On" switch (GYRO). Wait 10 minutes for complete GYRO wind up. DO NOT JOSTLE OR MOVE TRAILER DURING WIND-UP.

2.--Place "UN-CAGE" switch in UP position. A noise will be heard for a few seconds; if the noise should continue for more than a few seconds flip the "UN-CAGE" switch to OFF and initiate the operation again. It is not necessary to turn the "SYSTEMS ON" switch off again.

3.--Start the gasoline driven generator for a warm up period of one to two minutes. Then activate the Skid Truck "SYSTEMS ON" switch. Zero the recorder.

4.--Perform the BLOCK calibration.

SHUT DOWN

1.--Stop vehicle, preferable on a level spot. Flip both "SYSTEMS ON" and "UNCAGE" off and allow 20 minutes for wind down before moving trailer.

APPENDIX B

SPECIFICATIONS FOR THE VERTICAL GYROSCOPE

SPECIFICATIONS
for the
VERTICAL GYROSCOPE

I. Electrical Characteristics

A. Spin Motor

Voltage 115 VAC, 400 Hertz, Single Phase

Power 50 Watts Starting, 20 Watts Running

B. Gaging Circuit

Voltage 28 VDC

Power 42 Watts Maximum

II. Caging Time 10 Seconds Nominal

III. Caging Accuracy Within 0.5% of Electrical Center

*IV. Potentiometer Characteristics

A. Roll and Pitch Pots

* Resistance 5000 $\pm$ 5.0% Ohms

Resolution 400 Turns Minimum

Power Dissipation 0.5 Watts Maximum

* Linearity 0.5% Maximum

* Active Elements - $\pm$ 20° $\pm$ 2°

V. Mechanical Freedom

A. Roll Axis 360°

B. Pitch Axis $\pm$ 87°

*VI. Free Gyro Drift 0.5°/Min. Maximum Average Drift. Drift test to be conducted on a Scorsby Table set at $\pm$ 7.5° roll, pitch and yaw at rate of 0.1 Hertz. Scorsby table to be on automatic reversing during test. Gyro displacement due to earth's rotation to be corrected for, when computing drift rate.

VII. Erection Motors

*A. Voltage - 27 to 30 VAC, 380 to 420 Hertz, Single Phase

B. Power 6 Watts Nominal

*C. Accuracy $\pm$ 0.15° of True Vertical

D. Erection Rate 4 to 6°/Minute

VIII. Remarks

A. Items marked with (*) are checked on order by production tests. Other items for reference may be checked on order by qualification tests.

B. This instrument consists of a Minneapolis Honeywell Vertical Gyro Number JC044A-4 modified to the above specifications.

The above specifications were used by Humphrey Inc., San Diego, California.

APPENDIX C

DATA COLLECTED IN THE CORRELATION OF MECHANICAL AND DYNAMIC MEASURING DEVICES

LOCATION #1
DEGREE OF CURVE 4° RT
TYPE D HMAC (LIMESTONE)

	1WB		1EB	
	Mech.	Dynamic	Mech.	Dynamic
	-2°00'	-1°50'	2°56'	2°33'
	-2°00'	-1°48'	2°52'	2°36'
	-1°46'	-1°45'	2°52'	2°42'
	-1°46'	-1°42'	3°02'	2°48'
	-1°38'	-1°30'	3°14'	2°57'
	-1°30'	-1°24'	3°14'	3°06'
	-1°18'	-1°12'	3°30'	3°18'
	-1°18'	-1°12'	3°38'	3°33'
	-1°30'	-1°21'	3°40'	3°39'
	-1°32'	-1°30'	3°54'	3°48'
	-2°00'	-1°48'	4°08'	3°48'
	-2°18'	-2°00'	4°08'	3°42'
	-2°18'	-2°12'	3°52'	3°30'
	-2°30'	-2°18'	3°46'	3°18'
	-2°36'	-2°24'	3°32'	3°06'
	-2°26'	-2°27'	3°30'	2°57'
	-2°00'	-2°24'	3°12'	2°37'
	-1°44'	-2°18'	2°52'	2°27'
	-1°38'	-1°42'	2°44'	2°22'
	-1°12'	-1°24'	2°44'	2°21'
	-1°00'	-1°12'	2°36'	2°15'
Mean Dec.	-1.8095°	-1.7802°	3.3302°	3.0183°
SD Dec.	0.4474°	0.4266°	0.4780°	0.5138°
SD Deg.	0°27'	0°26'	0°28'	0°31'
Mean Deg.	-1°49'	-1°47'	3°20'	3°01'

LOCATION #2
DEGREE OF CURVE 3° RT
TYPE D HMAC (LIMESTONE)

	2WB		2EB	
	Mech.	Dynamic	Mech.	Dynamic
	-1°24'	-1°06'	2°02'	1°48'
	-1°32'	-1°36'	2°00'	1°44'
	-1°46'	-1°56'	1°54'	1°36'
	-1°46'	-2°00'	1°40'	1°28'
	-1°46'	-2°00'	1°40'	1°24'
	-1°36'	-1°56'	1°36'	1°20'
	-1°24'	-1°48'	1°36'	1°20'
	-1°12'	-1°34'	1°38'	1°32'
	-0°50'	-1°22'	1°50'	1°38'
	-0°50'	-1°06'	1°54'	1°44'
	-0°50'	-0°48'	2°02'	1°56'
	-0°38'	-0°44'	2°09'	2°06'
	-0°38'	-0°40'	2°09'	2°06'
	-0°48'	-0°34'	2°28'	2°24'
	-0°54'	-0°42'	2°28'	2°25'
	-1°12'	-0°54'	2°28'	2°30'
	-1°18'	-1°06'	2°30'	2°26'
	-1°18'	-1°20'	2°36'	2°30'
	-1°14'	-1°28'	2°38'	2°34'
	-1°14'	-1°24'	2°42'	2°36'
	-1°18'	-1°10'	2°50'	2°44'
Mean Dec.	-1.2127°	-1.2968°	2.1349°	1.9929°
SD Dec.	0.3632°	0.4693°	0.4024°	0.4739°
SD Deg.	0°22'	0°28'	0°24'	0°28'
Mean Deg.	-1°13'	-1°18'	2°08'	2°00'

LOCATION #3
DEGREE OF CURVE 4° RT
TYPE D HMAC (LIMESTONE)

	3WB		3EB	
	Mech.	Dynamic	Mech.	Dynamic
	-1°30'	-1°26'	2°30'	2°26'
	-1°38'	-1°26'	2°18'	2°24'
	-1°44'	-1°24'	2°20'	2°18'
	-1°44'	-1°24'	2°10'	2°14'
	-1°44'	-1°20'	2°10'	2°14'
	-1°44'	-1°14'	2°04'	2°06'
	-1°56'	-1°24'	2°00'	2°00'
	-2°14'	-1°48'	2°00'	2°08'
	-2°24'	-2°14'	2°04'	2°26'
	-2°18'	-2°12'	2°18'	2°36'
	-1°54'	-1°48'	2°32'	2°50'
	-1°54'	-1°30'	2°50'	3°06'
	-1°42'	-1°30'	2°38'	3°06'
	-1°42'	-1°14'	2°46'	2°56'
	-1°42'	-1°16'	2°38'	2°54'
	-1°42'	-1°18'	2°30'	2°48'
	-1°44'	-1°18'	2°18'	2°30'
	-1°54'	-1°26'	2°10'	2°24'
	-1°44'	-1°34'	1°54'	2°12'
	-1°38'	-1°18'	1°44'	2°04'
	-1°24'	-1°12'	1°38'	1°54'
Mean Dec.	-1.8064°	-1.4889°	2.2633°	2.4572°
SD Dec.	0.2467°	0.2903°	0.3239°	0.3628°
SD Deg.	0°15'	0°17'	0°19'	0°22'
Mean Deg.	-1°48'	-1°29'	2°16'	2°27'

LOCATION #4
DEGREE OF CURVE 10° LT.
TYPE D HMAC (LIMESTONE)

	4WB		4EB	
	Mech.	Dynamic	Mech.	Dynamic
	3°26'	3°54'	-1°30'	-1°30'
	3°40'	4°06'	-1°42'	-1°36'
	3°32'	4°04'	-1°50'	-1°39'
	3°32'	4°00'	-1°36'	-1°24'
	3°40'	4°12'	-1°24'	-1°30'
	3°54'	4°30'	-1°36'	-1°30'
	4°10'	4°40'	-1°36'	-1°42'
	4°32'	4°54'	-1°56'	-1°57'
	4°40'	5°12'	-2°04'	-2°06'
	4°40'	5°24'	-2°20'	-2°18'
	4°40'	5°24'	-2°10'	-2°12'
	4°26'	5°12'	-1°42'	-1°48'
	4°16'	4°48'	-1°38'	-1°30'
	4°02'	4°36'	-1°38'	-1°30'
	3°44'	4°20'	-1°54'	-1°46'
	3°44'	4°10'	-1°54'	-1°48'
	3°44'	4°10'	-1°54'	-1°48'
	3°40'	4°00'	-1°46'	-1°46'
	3°32'	3°56'	-1°42'	-1°42'
	3°20'	3°48'	-1°30'	-1°36'
	3°04'	3°32'	-1°30'	-1°30'
Mean Dec.	3.9032°	4.4222°	-1.7556°	-1.7206°
SD Dec.	0.4773°	0.5502°	0.2381°	0.2465°
SD Deg.	0°29'	0°33'	0°14'	0°15'
Mean Deg.	3°54'	4°25'	-1°45'	-1°43'

LOCATION #5
DEGREE OF CURVE 10° RT
TYPE D HMAC (LIMESTONE)

	5WB		5EB	
	Mech.	Dynamic	Mech.	Dynamic
	-2°30'	-2°24'	4°40'	4°36'
	-3°02'	-2°54'	5°04'	4°58'
	-2°32'	-3°12'	5°16'	5°00'
	-3°26'	-3°28'	5°22'	5°02'
	-3°40'	-3°40'	5°26'	5°12'
	-3°50'	-3°48'	5°36'	5°18'
	-3°58'	-3°58'	5°58'	5°48'
	-4°14'	-4°06'	5°52'	5°24'
	-4°14'	-4°12'	5°44'	5°24'
	-4°22'	-4°12'	5°44'	5°30'
	-4°22'	-4°22'	5°36'	5°20'
	-4°28'	-4°32'	5°18'	5°06'
	-4°22'	-4°34'	5°18'	5°08'
	-4°28'	-4°36'	5°42'	5°22'
	-4°22'	-4°34'	5°36'	5°36'
	-4°14'	-4°30'	5°26'	5°14'
	-4°08'	-4°20'	5°18'	5°18'
	-4°10'	-4°18'	5°18'	5°14'
	-4°20'	-4°14'	5°06'	5°10'
	-4°20'	-4°12'	5°06'	5°08'
	-3°54'	-4°14'	5°02'	5°14'
Mean Dec.	-3.9492°	-4.0159°	5.4032°	5.2397°
SD Dec.	0.5982°	0.5896°	0.3159°	0.2478°
SD Deg.	0°36'	0°35'	0°19'	0°15'
Mean Deg.	-3°57'	-4°01'	5°24'	5°14'

LOCATION #6
DEGREE OF CURVE 2° S LT.
TYPE D HMAC (LIMESTONE)

	6NB		6SB	
	Mech.	Dynamic	Mech.	Dynamic
	2°22'	2°10'	-2°14'	-2°00'
	2°22'	2°06'	-2°18'	-2°10'
	2°24'	2°10'	-2°22'	-2°12'
	2°20'	2°10'	-2°36'	-2°24'
	2°24'	2°04'	-2°40'	-2°30'
	2°20'	1°56'	-2°40'	-2°30'
	2°10'	1°56'	-2°40'	-2°36'
	2°20'	2°00'	-2°52'	-2°42'
	2°20'	2°04'	-2°50'	-2°30'
	2°20'	2°10'	-2°38'	-2°24'
	2°22'	2°06'	-2°22'	-2°18'
	2°36'	2°24'	-2°18'	-2°10'
	2°46'	2°32'	-2°10'	-2°00'
	2°46'	2°34'	-2°10'	-1°54'
	2°52'	2°36'	-2°10'	-1°54'
	2°44'	2°36'	-2°04'	-1°54'
	2°36'	2°24'	-2°04'	-1°54'
	2°22'	2°12'	-2°04'	-1°54'
	2°20'	2°06'	-2°08'	-1°54'
	2°24'	2°06'	-2°08'	-2°00'
	2°24'	2°00'	-2°04'	-2°02'
Mean Dec.	2.4556°	2.2081°	-2.3586°	-2.1842°
SD Dec.	0.1869°	0.2175°	0.2717°	0.2697°
SD Deg.	0°11'	0°13'	0°16'	0°16'
Mean Deg.	2°27'	2°12'	-2°22'	-2°11'

LOCATION #7
DEGREE OF CURVE 2° S LT.
TYPE D HMAC (LIMESTONE)

	7NB		7SB	
	Mech.	Dynamic	Mech.	Dynamic
	2°30'	1°56'	-2°52'	-3°12'
	2°52'	1°52'	-2°40'	-3°08'
	2°18'	1°48'	-2°40'	-3°06'
	2°30'	1°52'	-2°40'	-3°00'
	2°30'	2°00'	-2°38'	-2°44'
	2°30'	2°08'	-2°22'	-2°42'
	2°30'	2°00'	-2°08'	-2°30'
	2°20'	1°58'	-2°08'	-2°30'
	2°30'	2°00'	-2°18'	-2°26'
	2°30'	2°06'	-2°04'	-2°20'
	2°36'	2°10'	-1°56'	-2°12'
	2°24'	2°04'	-1°44'	-2°00'
	2°10'	1°54'	-1°44'	-2°02'
	2°30'	2°00'	-1°44'	-1°58'
	2°20'	1°56'	-1°54'	-2°04'
	2°10'	1°54'	-2°04'	-2°12'
	2°18'	1°46'	-2°04'	-2°18'
	2°04'	1°36'	-2°10'	-2°24'
	2°04'	1°40'	-2°04'	-2°26'
	2°04'	1°40'	-2°14'	-2°28'
	2°04'	1°38'	-2°14'	-2°30'
Mean Dec.	2.3683°	1.9032°	-2.2081°	-2.5175°
SD Dec.	0.2119°	0.1643°	0.3331°	0.3556°
SD Deg.	0°13'	0°10'	0°20'	0°21'
Mean Deg.	2°22'	1°54'	-2°12'	-2°31'

LOCATION #8
DEGREE OF CURVE - TANGENT
GR. 4 SEAL COAT - LIMESTONE (DOLOMITE)

	8NB		8SB	
	Mech.	Dynamic	Mech.	Dynamic
	1°54'	1°52'	0°32'	0°24'
	1°54'	1°56'	0°42'	0°20'
	1°54'	1°54'	0°28'	0°12'
	1°50'	1°48'	0°30'	0°08'
	1°40'	1°42'	0°36'	0°04'
	1°32'	1°36'	0°24'	0°08'
	1°32'	1°30'	0°24'	0°12'
	1°32'	1°24'	0°30'	0°24'
	1°24'	1°18'	0°40'	0°36'
	1°16'	1°14'	0°52'	0°42'
	1°12'	1°04'	0°56'	0°44'
	1°12'	1°04'	0°48'	0°50'
	1°18'	1°08'	1°00'	0°58'
	1°04'	1°04'	1°08'	1°12'
	1°30'	1°08'	1°30'	1°24'
	1°18'	1°18'	1°26'	1°36'
	1°38'	1°24'	1°40'	1°48'
	1°36'	1°36'	2°04'	2°04'
	1°44'	1°38'	2°04'	2°18'
	1°04'	1°42'	2°04'	2°08'
	1°36'	1°42'	1°56'	2°00'
Mean Dec.	1.5078°	1.4778°	1.0589°	0.9619°
SD Dec.	0.2658°	0.2933°	0.6025°	0.7567°
SD Deg.	0°16'	0°18'	0°36'	0°45'
Mean Deg.	1°30'	1°29'	1°04'	0°58'

LOCATION #9
DEGREE OF CURVE - 1° LT.
GR. 4 SEAL COAT (DOLOMITE)

	9NB		9SB	
	Mech.	Dynamic	Mech.	Dynamic
	2°46'	2°52'	-1°18'	-1°18'
	2°46'	2°48'	-1°24'	-1°24'
	2°52'	2°46'	-1°30'	-1°26'
	2°52'	2°46'	-1°14'	-1°12'
	2°44'	2°46'	-1°08'	-1°00'
	2°44'	2°36'	-0°48'	-0°36'
	2°40'	2°32'	-0°36'	-0°24'
	2°30'	2°28'	-0°48'	-0°30'
	2°36'	2°30'	-0°48'	-0°32'
	2°22'	2°24'	-0°56'	-0°42'
	2°36'	2°32'	-1°04'	-0°48'
	2°40'	2°36'	-1°08'	-0°54'
	2°36'	2°30'	-1°04'	-0°54'
	2°30'	2°26'	-1°16'	-0°50'
	2°18'	2°20'	-1°16'	-0°48'
	2°24'	2°14'	-1°16'	-0°50'
	2°10'	2°06'	-1°16'	-0°54'
	2°20'	2°06'	-1°08'	-0°56'
	2°08'	2°06'	-1°14'	-1°00'
	2°14'	2°00'	-1°14'	-1°08'
	2°06'	1°58'	-1°14'	-1°14'
Mean Dec.	2.5191°	2.4460°	-1.1270°	-0.9206°
SD Dec.	0.2419°	0.2764°	0.2248°	0.2886°
SD Deg.	0°14'	0°17'	0°13'	0°17'
Mean Deg.	2°31'	2°27'	-1°08'	-0°55'

LOCATION #10
DEGREE OF CURVE 2°30' RT.
GR. 4 SEAL COAT LIMESTONE (DOLOMITE)

	10NB		10SB	
	Mech.	Dynamic	Mech.	Dynamic
	-2°22'	-2°18'	4°20'	4°00'
	-2°50'	-2°42'	4°20'	4°00'
	-2°58'	-2°48'	4°10'	4°00'
	-2°56'	-2°56'	4°10'	4°10'
	-3°04'	-3°00'	4°26'	4°06'
	-2°52'	-3°00'	4°26'	4°12'
	-2°52'	-2°50'	4°14'	4°18'
	-2°40'	-2°42'	4°14'	4°24'
	-2°32'	-2°44'	4°14'	4°18'
	-2°40'	-2°36'	4°14'	4°18'
	-2°30'	-2°34'	3°54'	4°00'
	-2°30'	-2°36'	3°54'	3°54'
	-2°40'	-2°36'	3°50'	3°48'
	-3°04'	-2°50'	3°50'	3°48'
	-3°08'	-2°54'	3°52'	4°00'
	-2°56'	-2°54'	3°52'	4°06'
	-2°50'	-2°56'	4°04'	4°16'
	-2°50'	-2°48'	4°04'	4°16'
	-3°02'	-2°42'	4°04'	4°16'
	-2°56'	-2°42'	4°20'	4°24'
	-2°56'	-2°48'	4°10'	4°30'
Mean Dec.	-2.8159°	-2.7587°	4.1286°	4.1460°
SD Dec.	0.2128°	0.1690°	0.1984°	0.1979°
SD Deg.	0°13'	0°10'	0°12'	0°12'
Mean Deg.	-2°49'	-2°46'	4°08'	4°09'

LOCATION #11
DEGREE OF CURVE - TANGENT
SURFACE TREATMENT

	11NEB		11SWB	
	Mech.	Dynamic	Mech.	Dynamic
	2°30'	3°24'	1°54'	1°48'
	2°18'	3°06'	1°54'	1°40'
	2°04'	3°00'	2°04'	1°30'
	2°04'	3°06'	1°44'	1°30'
	2°14'	3°00'	1°44'	1°24'
	2°08'	3°06'	1°42'	1°14'
	2°04'	3°00'	1°30'	1°18'
	1°56'	2°54'	1°30'	1°18'
	1°56'	2°48'	1°30'	1°18'
	1°42'	2°30'	1°30'	1°18'
	1°36'	2°36'	1°30'	1°24'
	1°54'	2°42'	1°30'	1°30'
	2°06'	2°56'	1°30'	1°30'
	2°18'	3°06'	1°42'	1°36'
	2°28'	3°12'	1°42'	1°36'
	2°14'	3°18'	1°42'	1°30'
	2°10'	3°12'	1°36'	1°42'
	2°24'	3°08'	2°06'	2°06'
	2°00'	2°54'	2°18'	2°00'
	1°54'	2°42'	2°24'	2°06'
	1°54'	2°40'	2°20'	2°12'
Mean Dec.	2.0905°	2.9683°	1.7794°	1.5952°
SD Dec.	0.2348°	0.2379°	0.2988°	0.2914°
SD Deg.	0°14'	0°14'	0°18'	0°17'
Mean Deg.	2°05'	2°58'	1°47'	1°36'

LOCATION #12
DEGREE OF CURVE 5° RT.
SURFACE TREATMENT

	12NEB		12SWB	
	Mech.	Dynamic	Mech.	Dynamic
	-2°44'	-2°28'	4°20'	3°26'
	-2°44'	-2°28'	4°22'	3°26'
	-2°44'	-2°18'	4°16'	3°30'
	-2°32'	-2°18'	4°08'	3°36'
	-2°18'	-2°00'	3°58'	3°34'
	-2°04'	-2°00'	3°52'	3°34'
	-1°56'	-1°48'	4°08'	3°30'
	-2°00'	-1°48'	4°04'	3°24'
	-2°24'	-1°48'	4°14'	3°24'
	-2°10'	-1°54'	4°04'	3°30'
	-2°30'	-1°48'	3°50'	3°36'
	-2°36'	-2°12'	3°58'	3°32'
	-2°36'	-2°12'	4°04'	3°32'
	-2°36'	-2°06'	4°10'	3°42'
	-2°52'	-2°10'	4°10'	3°48'
	-2°52'	-2°30'	4°10'	3°54'
	-2°52'	-2°36'	4°14'	3°54'
	-3°12'	-2°36'	4°26'	4°06'
	-3°12'	-2°48'	4°22'	4°12'
	-3°02'	-2°48'	4°34'	4°18'
	-2°44'	-2°30'	4°40'	4°20'
Mean Dec.	-2.6032°	-2.2429°	4.1937°	3.7048°
SD Dec.	0.3615°	0.3290°	0.2128°	0.3012°
SD Deg.	0°22'	0°20'	0°13'	0°18'
Mean Deg.	-2°36'	-2°15'	4°12'	3°42'

LOCATION #13
DEGREE OF CURVE - TANGENT
TYPE D HMAC (LIMESTONE)

	13NB		13SB	
	Mech.	Dynamic	Mech.	Dynamic
	1°12'	1°14'	1°16'	1°06'
	1°00'	1°12'	1°24'	1°18'
	1°04'	1°08'	1°32'	1°30'
	1°04'	1°06'	1°44'	1°48'
	1°04'	1°12'	1°44'	1°44'
	1°18'	1°20'	1°30'	1°36'
	1°18'	1°26'	1°24'	1°30'
	1°18'	1°24'	1°14'	1°18'
	1°24'	1°32'	1°16'	1°14'
	1°30'	1°34'	1°24'	1°20'
	1°30'	1°36'	1°16'	1°24'
	1°30'	1°36'	1°12'	1°12'
	1°30'	1°36'	1°38'	1°24'
	1°30'	1°36'	1°32'	1°42'
	1°30'	1°34'	1°32'	1°42'
	1°16'	1°25'	1°44'	1°48'
	1°12'	1°24'	1°46'	1°52'
	1°04'	1°22'	1°46'	1°52'
	1°04'	1°12'	1°42'	1°52'
	1°04'	1°08'	1°42'	1°46'
	1°16'	1°06'	1°30'	1°34'
Mean Dec.	1.2683°	1.3675°	1.5143°	1.5492°
SD Dec.	0.1827°	0.1855°	0.1945°	0.2451°
SD Deg.	0°11'	0°11'	0°12'	0°15'
Mean Deg.	1°16'	1°22'	1°31'	1°33'

LOCATION #14
DEGREE OF CURVE 3°S RT.
LIGHTWEIGHT SURFACE - TREATMENT

	14NB	
	Mech.	Dynamic
	-2°06'	-1°48'
	-2°06'	-1°48'
	-2°06'	-1°48'
	-2°10'	-1°48'
	-2°14'	-1°54'
	-2°30'	-2°00'
	-2°36'	-2°12'
	-2°36'	-2°16'
	-2°36'	-2°14'
	-2°36'	-2°08'
	-2°36'	-2°08'
	-2°36'	-2°12'
	-2°40'	-2°18'
	-2°44'	-2°22'
	-2°56'	-2°30'
	-2°56'	-2°30'
	-2°58'	-2°30'
	-2°58'	-2°44'
	-2°44'	-2°36'
	-2°46'	-2°30'
	-2°44'	-2°26'
Mean Dec.	-2.5825°	-2.2238°
SD Dec.	0.2874°	0.2889°
SD Deg.	0°17'	0°17'
Mean Deg.	-2°35'	-2°13'

LOCATION #15
DEGREE OF CURVE - RT.
SURFACE TREATMENT

	15NEB		15SWB	
	Mech.	Dynamic	Mech.	Dynamic
	-3°44'	-3°48'	3°44'	3°34'
	-3°44'	-3°44'	3°44'	3°34'
	-3°44'	-3°44'	3°40'	3°36'
	-3°40'	-3°32'	3°44'	3°42'
	-3°38'	-3°34'	3°50'	3°48'
	-3°38'	-3°36'	3°50'	3°50'
	-3°38'	-3°34'	3°58'	3°54'
	-3°40'	-3°42'	3°58'	3°54'
	-3°40'	-3°42'	3°50'	3°44'
	-3°40'	-3°42'	3°44'	3°38'
	-3°44'	-3°42'	3°44'	3°38'
	-3°50'	-3°52'	3°46'	3°40'
	-3°54'	-3°54'	3°50'	3°46'
	-4°02'	-3°54'	3°44'	3°44'
	-3°58'	-3°50'	3°52'	3°44'
	-3°50'	-3°36'	3°54'	3°54'
	-3°38'	-3°24'	3°54'	4°00'
	-3°44'	-3°24'	4°04'	4°00'
	-3°44'	-3°28'	3°50'	4°00'
	-3°44'	-3°36'	3°50'	3°54'
	-3°58'	-3°48'	3°44'	3°48'
Mean Dec.	-3.7556°	-3.6714°	3.8206°	3.7794°
SD Dec.	0.1213°	0.1514°	0.0997°	0.1412°
SD Deg.	0°07'	0°09'	0°06'	0°08'
Mean Deg.	-3°45'	-3°40'	3°49'	3°47'

APPENDIX D

TABLES & EQUATIONS

FOR
ASPHALTIC CONCRETE MIX DESIGN
FOR
PREDETERMINING SKID RESISTANCE

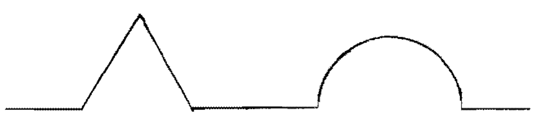
TABLE VIII

PREDICTION OF THE "E + C" TEXTURE VALUES FROM THE POLISH VALUE

E+C TEXTURE VALUE	POLISH VALUE
E 5	60
E 4	50
E 3	40
E 2	30
E 1	20

1

Polished (No Texture Visible)

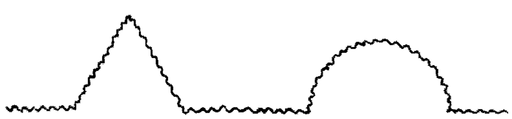


2

Smooth (Texture Visible But Micro — Projections Too Small For Visual Estimate Of Height

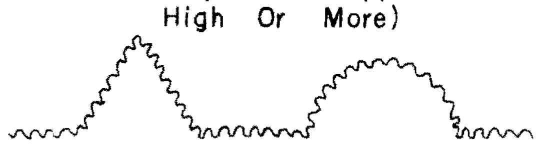
3

Fine Grained (Micro – Pro – jections Appr. 1/4 mm High)



4

Coarse Grained – Subangular (Micro – Projections Appr. 1/2 mm High Or More)



5

Coarse Grained — Angular (Micro – Projections Appr. 1/2 mm High Or More)

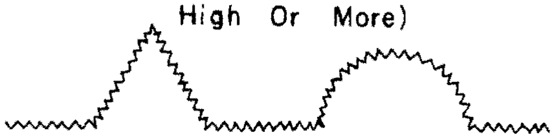


TABLE IX

COARSE AGGREGATE HEIGHT ADJUSTMENT FACTOR FOR ATTRITION LOSS

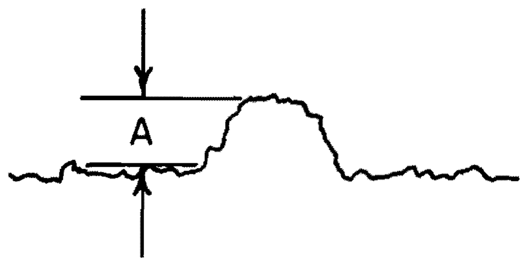
ESTIMATED ADT	L.A. ABRASION VALUE	ADJUSTMENT FACTOR
LESS THAN 2,000	LESS THAN 20	0.95
	20 – 29	0.90
	30 – 39	0.80
	GREATER THAN 39	0.65
2,000 TO 10,000	LESS THAN 20	0.98
	20 – 29	0.95
	30 – 39	0.89
	GREATER THAN 39	0.80
GREATER THAN 10,000	LESS THAN 20	1.00
	20 – 29	0.98
	30 – 39	0.94
	GREATER THAN 39	0.88

NOTE: The L.A. Abrasion Value Should Be That Of The Material Which Dominates The Coarse Aggregate Portion Of The Mix.

TABLE X

HEIGHT PARAMETER A

MEASURED IN MILLIMETERS FROM THE TOP OF THE BACKGROUND TO THE TOP OF THE PROJECTION

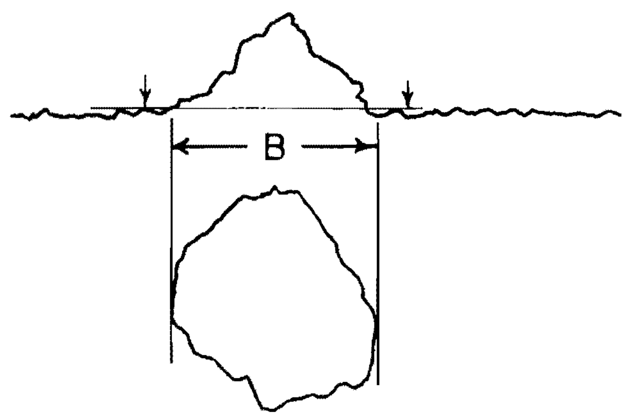


HEIGHT VALUE	HEIGHT IN mm
A 0	0 mm
A 1	1/4 mm
A 2	1/2 mm
A 3	1 mm
A 4	2 mm
A 5	4 mm
A 6	8 mm

TABLE XI

WIDTH PARAMETER B

MEASURED IN MILLIMETERS AND IS THE HORIZONTAL DIMENSION OF THE PROJECTION — MEASURED AT THE LEVEL OF THE TOP OF THE BACKGROUND



WIDTH VALUE	WIDTH IN mm
B 0	16 mm
B 1	8 mm
B 2	4 mm
B 3	2 mm

NOTE: Particles Less Than 2 mm Wide Are Regarded As Background.

TABLE XII

DENSITY PARAMETER D

DENSITY VALUE	PERCENT OF TOTAL AREA COVERED BY ASPERITIES
D 0	0 %
D 1	25 %
D 2	50 %
D 3	75 %
D 4	100 %

TABLE XIII

FINE TEXTURE OF BACKGROUND PARAMETER F

DENOTES SIZE, SHARPNESS OR ROUNDNESS OF THE MICRO—PROJECTIONS IN THE BACKGROUND

1

Polished (No Texture Visible)

2

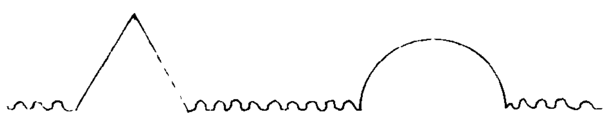
Smooth (Texture Visible But Micro — Projections Too Small For Visual Estimate Of Height)

3

Fine Grained (Micro — Projections Appr. 1/4 mm High)

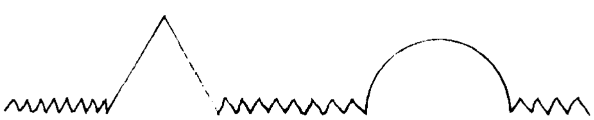
4

Coarse Grained—Subangular (Micro — Projections Appr. 1/2 mm High Or More)



5

Coarse Grained — Angular (Micro — Projections Appr. 1/2 mm High Or More)



EQUATION #1

$$FARF = \frac{50 + 0.5\ (IRP)}{100}$$

WHERE

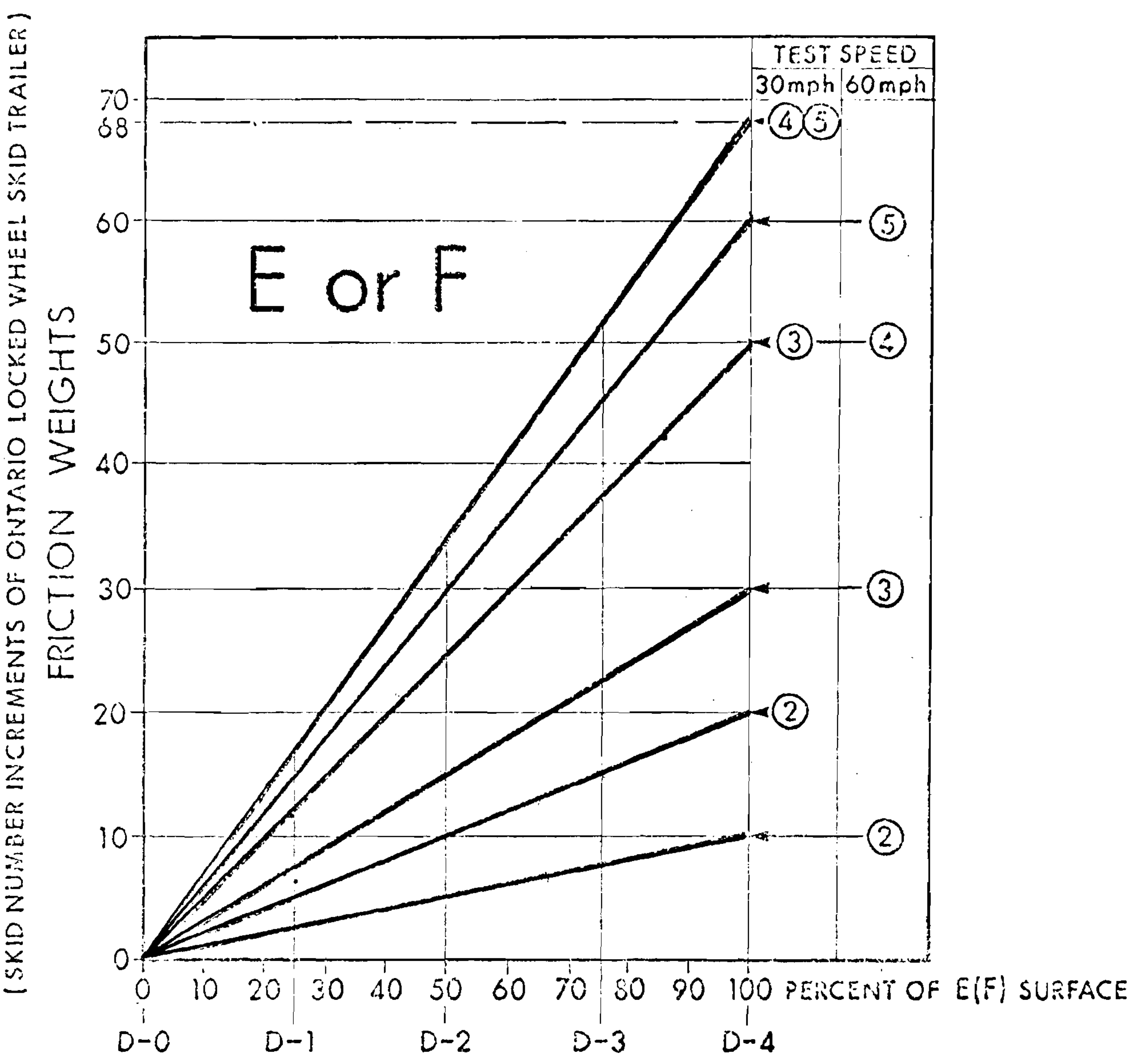
FARF = Fine Aggregate Reduction Factor
IRP = Insoluble Residue Percentage

NOTE: THE INSOLUBLE RESIDUE VALUE SHOULD BE THAT OF THE MATERIAL WHICH DOMINATES THE FINE AGGREGATE PORTION OF THE MIX.

ESTIMATES SHOULD BE MADE OF THE SHAPE OF THE FINE AGGREGATE; HOWEVER, IF THE INSOLUBLE RESIDUE PERCENTAGE IS LESS THAN 50%, IT SHALL BE ASSUMED THAT THE FINE AGGREGATE HAS ROUNDED.

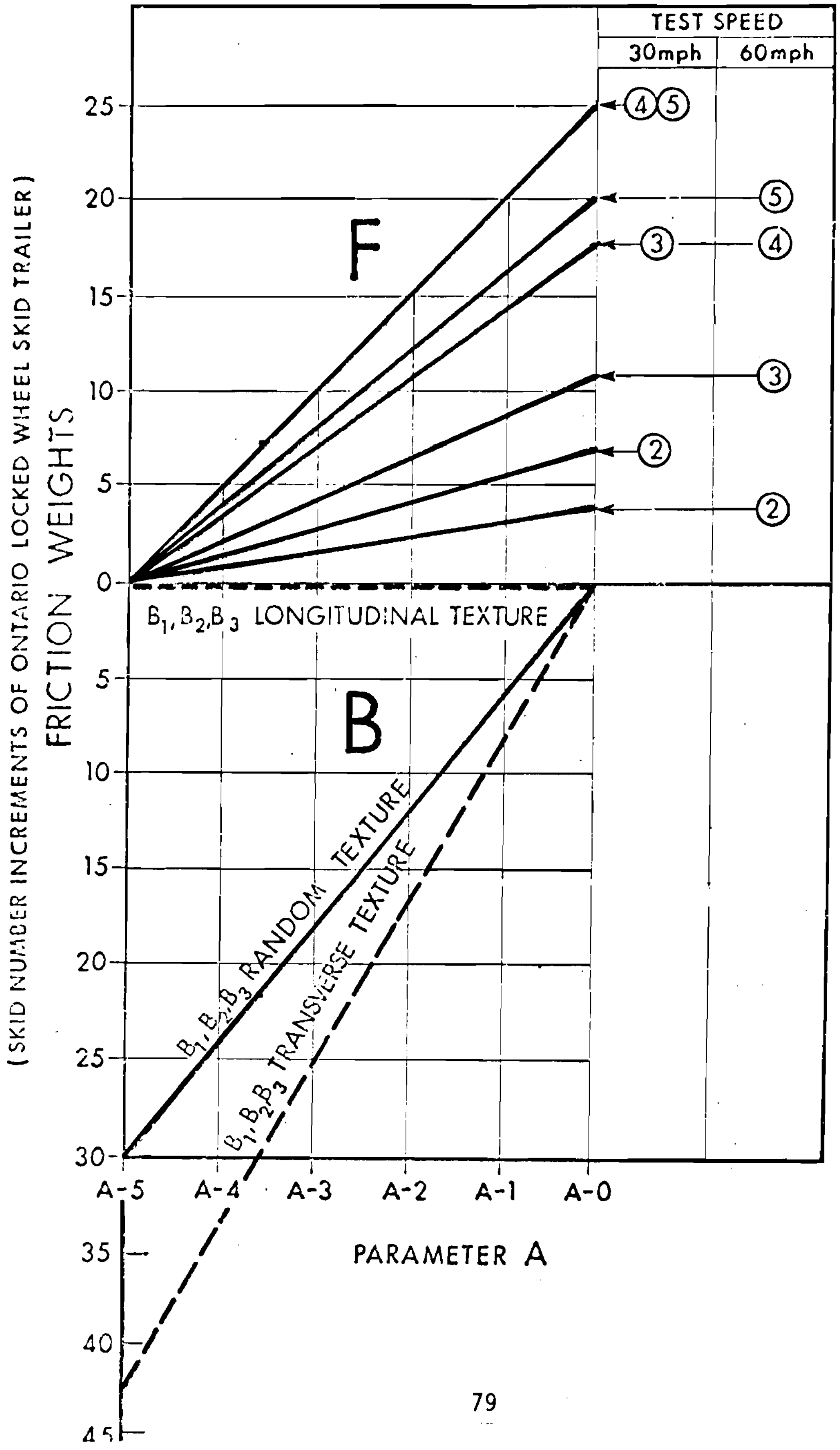
CHART NO. 1

SKID RESISTANCE PHOTO-INTERPRETATION
FRICTION WEIGHTS
OF PAVEMENT TEXTURE PARAMETER E
OR, IF MACRO-PROJECTIONS ARE ABSENT (D ZERO), OF PARAMETER F

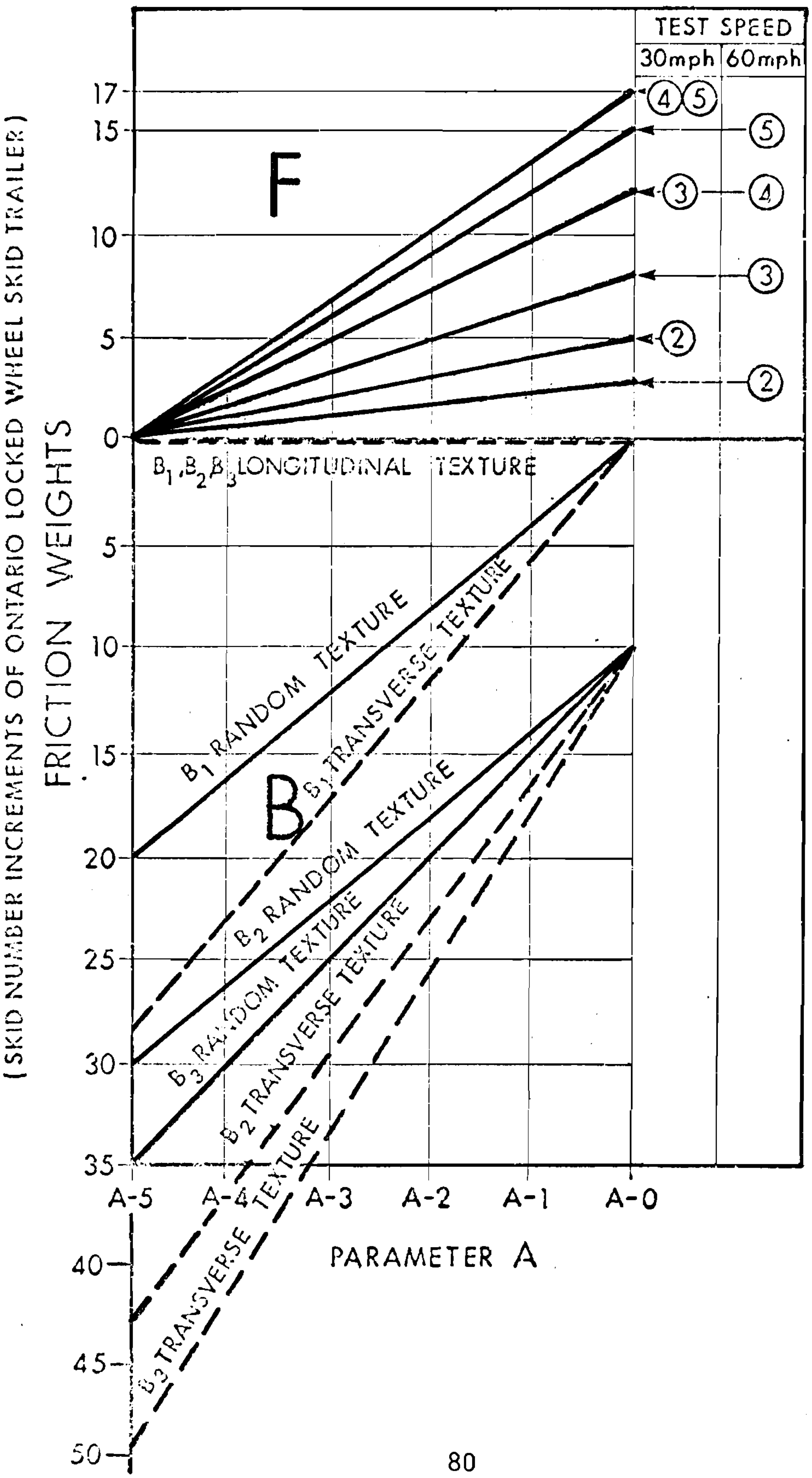


NOTE: IF THE DENSITY PARAMETER IS D–1, D–2 OR D–3, ADD TO THE FRICTION WEIGHT FOR PARAMETER E OBTAINED FROM THIS GRAPH THE FRICTION WEIGHTS FOR PARAMETERS A, B AND F OBTAINED FROM CHART NO. 2, CHART NO. 3 OR CHART NO. 4, RESPECTIVELY.

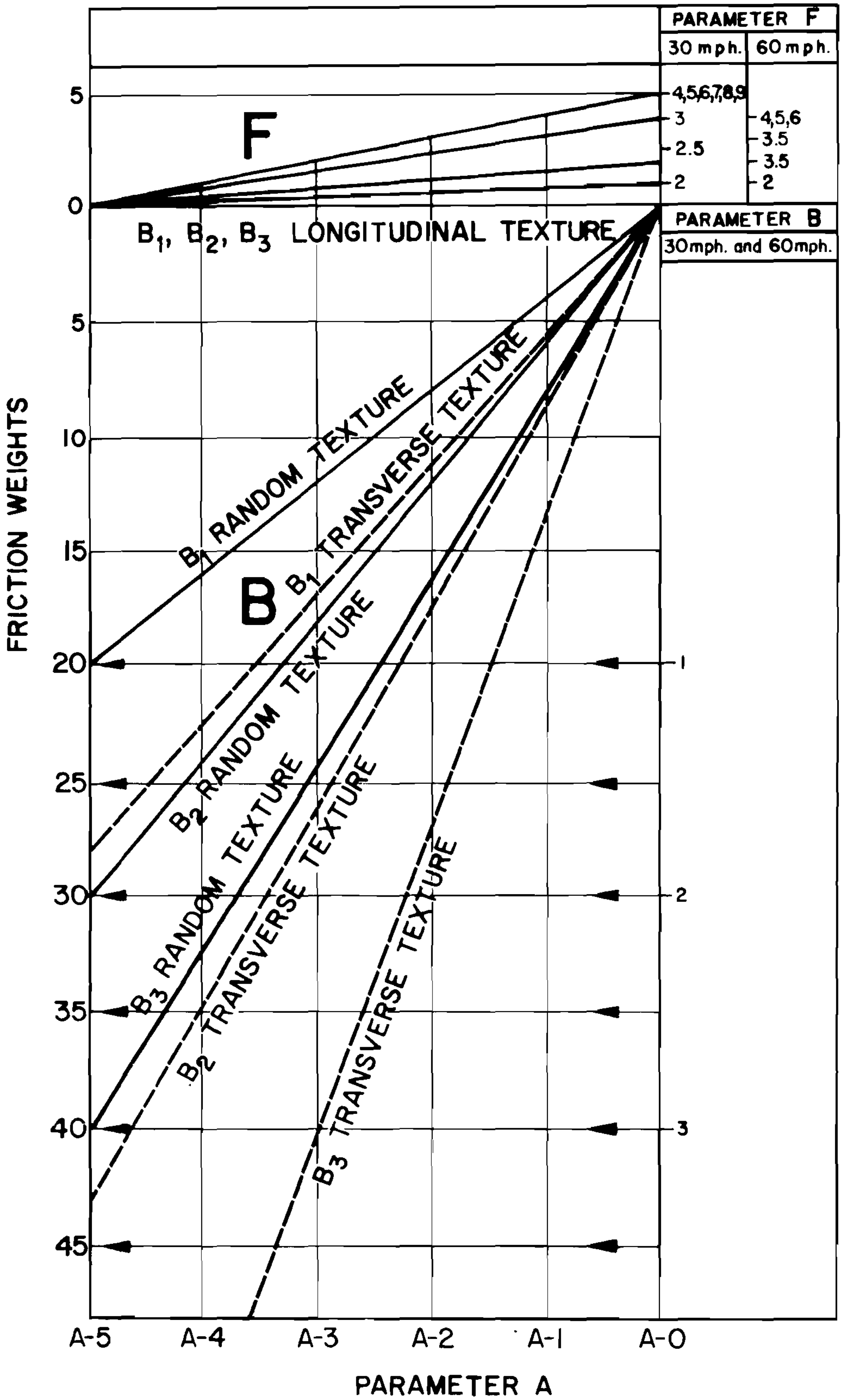
SKID RESISTANCE PHOTO-INTERPRETATION
FRICTION WEIGHTS
OF PAVEMENT TEXTURE PARAMETERS A, B AND F, FOR D 1



SKID RESISTANCE PHOTO-INTERPRETATION
FRICTION WEIGHTS
OF PAVEMENT TEXTURE PARAMETERS A, B AND F,
FOR D 2



SKID RESISTANCE PHOTO-INTERPRETATION
FRICTION WEIGHTS
OF TEXTURE PARAMETERS A,B, AND F
FOR D3



APPENDIX E

FORMS USED IN THE CALCULATIONS
on
ASPHALTIC CONCRETE MIX DESIGN
for
PREDETERMINING SKID RESISTANCE

TEXAS HIGHWAY DEPARTMENT
ASPHALTIC CONCRETE SIEVE ANALYSIS WORK SHEET

County__________ Highway__________ Project__________ Control__________

Date__________ Time__________ Station__________ Sampled By__________

Spec. Item__________ Type__________ Design No.__________

Sieve Size	Bin No. 1		(a)	Bin No. 2		(b)	Bin No. 3		(c)	Bin No. 4		(d)	Combined Analysis % (a+b+c+d)
	Weight (grams)	Total % x	%	Weight (grams)	Total % x	%	Weight (grams)	Total % x	%	Weight (grams)	Total % x	%	
1¾" — ⅞"													
⅞" — ⅝"													
⅝" — ⅜"													
½" — ⅜"													
⅜" — 4													
¼" — 10													
4 — 10													
+ 10													
10 — 40													
40 — 80													
80 — 200													
Pass 200													
Total	gm	100.0%	%	gm	100.0%	%	gm	100.0%	%	gm	100.0%	%	%

PER CENT MOISTURE IN AGGREGATES IN HOT BINS

Bin No.	(a) Tare Wt. (gms.)	(b) Gross Wet Wt. (gms.)	(c) Gross Dry Wt. (gms.)	(d) Wt. Moist (gms.) b-c	(e) Dry Wt. Aggr. (gms.) c-a	% Moist. $\frac{d}{e}$ x100%
1						
2						
3						
4						

Asphaltic Binder = __________%

Total = 100.0%

____

Inspector

FORM I

TEXAS HIGHWAY DEPARTMENT

COUNTY__________ HIGHWAY__________ PROJECT__________ CONTROL__________

DATE__________ TIME__________ STATION__________ SAMPLED BY__________

SPEC. ITEM__________ TYPE__________ DESIGN NO.__________

INS. RES.															
POLISH VALUE															
SIEVE SIZE (mm)	SIEVE SIZE (in.)	BIN NO. 1			BIN NO. 2			BIN NO. 3			BIN NO. 4			COMBINED ANALYSIS % BY VOLUME	
		% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.			
44.4 – 22.2	1 3/4" - 7/8"														
22.2 – 9.52	7/8" - 5/8"														
15.9 – 9.52	5/8" - 3/8"														
12.7 – 9.52	1/2" - 3/8"														
9.52 – 4.76	3/8" - 4														
6.35 – 2.00	1/4" - 10														
4.76 – 2.00	4 – 10														
+ 2.00	+ 10														=D
2.00 – 0.42	10 – 40														
0.42 – 0.177	40 – 80														
0.177 – 0.074	80 – 200														
– 0.074	PASS 200														
	TOTAL	%	%		%	%		%	%		%	%			

ASPHALTIC BINDER = ______ % BY WEIGHT = ______ % BY VOLUME

TOTAL______

PREPARED BY____________________

FORM 2

DETERMINATION OF VOLUMETRIC PERCENTAGES

	(a) PERCENT BY WEIGHT OF TOTAL MIX	(b) SPECIFIC GRAVITY OF MATERIAL	(c) $\frac{a}{b}$	(d) PERCENT BY VOLUME OF TOTAL MIX
BIN 1				
BIN 2				
BIN 3				
BIN 4				
ASPHALT				
TOTAL				

FORM 3

COARSE AGGREGATE-CALCULATIONS OF "A" AND "B"

(a) AVERAGE SIEVE SIZE (mm)	SIEVE SIZE	(b) COMBINED ANALYSIS % BY VOLUME	(c) a x b	(d) WEIGHTED AVERAGE SIZE $\frac{c}{b}$
11.11	$\frac{1}{2}$ - $\frac{3}{8}$			
7.14	$\frac{3}{8}$ - 4			
4.18	$\frac{1}{4}$ -10			
3.38	4-10			

$$A_u = 0.25 \times \frac{c}{b}$$

$A_u = 0.25 \times$ = mm

$$A_c = A_u \times \text{ADJUSTMENT FACTOR (TABLE IX)}$$

$A_c = \quad \times$ A=

$$B_c = 0.75 \times \frac{c}{b}$$

$B_c = 0.75 \times$ = mm B=

FINE AGGREGATE-CALCULATIONS OF "F

(d) AVERAGE SIEVE SIZE (mm)	SIEVE SIZE	(e) COMBINED ANALYSIS % BY VOLUME	(f) e x d	g WEIGHTED AVERAGE SIZE $\frac{f}{e}$
1.21	10-40			
0.30	40-80			
0.13	80-200			
0.04	-200			

$F_c = \frac{f}{e} \times$ FARF (EQUATION I)

F =

$F_c = \quad \times$

FORM 4

CALCULATIONS OF "E+C"

	(a) BIN 1	(b) BIN 2	(c) BIN 3	(d) BIN 4	(e)	(f)
% BY VOLUME OF +10 MESH						
POLISH VALUE						
TOTAL						

WEIGHTED POLISH VALUE = $\frac{e}{f}$

WEIGHTED POLISH VALUE = ________ =

E+C = __________ (From TABLE VIII)

FORM 5

DETERMINATION OF SKID QUALITIES OF ASPHALTIC CONCRETE MIX

TEXTURE PARAMETERS DETERMINED FOR MIX

A= ______

B= ______

D= ______

E+C= ______

F= ______

CHART LOCATION	TEXTILE PARAMETER CONSIDERED	FRICTION WEIGHT	
		30 mph	60 mph
CHART 1	E (or E+C)		
CHART 2,3 or 4 (Depending on D)	F		
CHART 2,3 or 4 (Depending on D)	B		
TOTAL FRICTION WEIGHT			

APPENDIX F

EXAMPLES OF CALCULATIONS
FOR
ASPHALTIC CONCRETE MIX DESIGN
FOR
PREDETERMINING SKID RESISTANCE

EXAMPLE I

L.A. Wear (abrasion) - BIN 3	= 20
Polish Value - BIN 3	= 24
- BIN 2	= 30
Insoluble Residue Test - BIN 1	= 85%
- BIN 2	= 5%
Expected ADT	= 22,500

Construction Form No. 544 Rev. (2)

TEXAS HIGHWAY DEPARTMENT
ASPHALTIC CONCRETE SIEVE ANALYSIS WORK SHEET

County Monroe Highway SH-2000 Project F-1 (234) Control 5-6

Date 9-4-67 Time Station Sampled By

Spec. Item 340 Type D Design No. Trial #1

Sieve Size	Bin No. 1 (a) Weight (grams)	Total %	x 30.8 %	Bin No. 2 (b) Weight (grams)	Total %	x 22.4 %	Bin No. 3 (c) Weight (grams)	Total %	x 40.0 %	Bin No. 4 (d) Weight (grams)	Total %	x %	Combined Analysis % (a+b+c+d)
1¾" — ⅞"													
⅞" — ⅝"													
⅝" — ⅜"													
½" — ⅜"							54	3.6	1.4				1.4
⅜" — 4				53	6.7	1.5	1326	89.5	35.8				37.3
¼" — 10													
4 — 10	36	8.3	2.6	688	86.4	19.4	34	2.3	0.9				22.9
+ 10			2.6			20.4			38.1				61.6
10 — 40	153	35.1	10.8	32	4.0	0.9	24	1.6	0.6				12.3
40 — 80	143	32.8	10.1	6	0.8	0.2	13	0.9	0.4				10.7
80 — 200	73	16.7	5.1	9	1.1	0.2	13	0.9	0.4				5.7
Pass 200	31	7.1	2.2	8	1.0	0.2	18	1.2	0.5				2.9
Total	436 gm	100.0%	30.8 %	796 gm	100.0%	22.4 %	1402 gm	100.0%	40.0 %	gm	100.0%	%	93.2 %

PER CENT MOISTURE IN AGGREGATES IN HOT BINS						
Bin No.	(a) Tare Wt. (gms.)	(b) Gross Wet Wt. (gms.)	(c) Gross Dry Wt. (gms.)	(d) Wt. Moist (gms.) b-c	(e) Dry Wt. Aggr. (gms.) c-a	% Moist. d/e x100%
1						
2						
3						
4						

Asphaltic Binder = 6.8 %

Total = 100.0%

J. S.

Inspector

FORM I

TEXAS HIGHWAY DEPARTMENT

COUNTY MONROE HIGHWAY SH-2000 PROJECT F I (234) CONTROL 5-6

DATE 9-4-67 TIME ____ STATION ____ SAMPLED BY ____

SPEC. ITEM 340 TYPE D DESIGN NO. Trial # 1

INS. RES.		85%			5%									
POLISH VALUE					30			24						
SIEVE SIZE (mm)	SIEVE SIZE (in.)	BIN NO. 1			BIN NO. 2			BIN NO. 3			BIN NO. 4			COMBINED ANALYSIS % BY VOLUME
		30.8	33.3		22.4	18.9		40.0	33.3					
		% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.		
44.4–22.2	1 3/4"–7/8"													
22.2–9.52	7/8"–5/8"													
15.9–9.52	5/8"–3/8"													
12.7–9.52	1/2"–3/8"							3.6	1.2					1.2
9.52–4.76	3/8"–4				6.7	1.3		89.5	29.8					31.1
6.35–2.00	1/4"–10													
4.76–2.00	4–10	8.3	2.8		86.4	16.2		2.3	0.8					19.8
+ 2.00	+10		2.8			17.5			31.8					51.2 =D
2.00–0.42	10–40	35.1	11.6		4.0	0.8		1.6	0.5					12.9
0.42–0.177	40–80	32.8	10.9		0.8	0.2		0.9	0.3					11.4
0.177–0.074	80–200	16.7	5.6		1.1	0.2		0.9	0.3					6.1
-0.074	PASS 200	7.1	2.4		1.0	0.2		1.2	0.4					3.0
	TOTAL	100.0%	33.3%		100.0%	18.9%		100.0%	33.3%		%	%		

ASPHALTIC BINDER = 6.8 % BY WEIGHT = 14.5 % BY VOLUME

TOTAL ____

PREPARED BY J. S.

FORM 2

DETERMINATION OF VOLUMETRIC PERCENTAGES

	(a) PERCENT BY WEIGHT OF TOTAL MIX	(b) SPECIFIC GRAVITY OF MATERIAL	(c) $\frac{a}{b}$	(d) PERCENT BY VOLUME OF TOTAL MIX
BIN 1	30.8	2.013	15.30	33.3
BIN 2	22.4	2.568	8.72	18.9
BIN 3	40.0	2.612	15.31	33.3
BIN 4				
ASPHALT	6.8	1.020	6.67	14.5
TOTAL			46.0	100.0

FORM 3

COARSE AGGREGATE-CALCULATIONS OF "A" AND "B"

(a) AVERAGE SIEVE SIZE (mm)	SIEVE SIZE	(b) COMBINED ANALYSIS % BY VOLUME	(c) a x b	(d) WEIGHTED AVERAGE SIZE $\frac{c}{b}$
11.11	$\frac{1}{2}-\frac{3}{8}$	1.2	13.33	
7.14	$\frac{3}{8}-4$	31.1	222.05	
4.18	$\frac{1}{4}-10$			
3.38	4-10	19.8	66.92	
		52.1	302.3	5.80

$A_u = 0.25 \times \frac{c}{b}$

$A_u = 0.25 \times 5.8 = 1.45$ mm

$A_c = A_u \times$ ADJUSTMENT FACTOR (TABLE IX)

$A_c = 1.45 \times 0.98 = 1.42$ A= 3

$B_c = 0.75 \times \frac{c}{b}$

$B_c = 0.75 \times 5.80 = 4.35$ mm B= 2

FINE AGGREGATE-CALCULATIONS OF "F

(d) AVERAGE SIEVE SIZE (mm)	SIEVE SIZE	(e) COMBINED ANALYSIS % BY VOLUME	(f) e x d	g WEIGHTED AVERAGE SIZE $\frac{f}{e}$
1.21	10-40	12.9	15.61	
0.30	40-80	11.4	3.42	
0.13	80-200	6.1	0.79	
0.04	-200	3.0	0.12	
		33.4	19.94	0.60

$F_c = \frac{f}{e} \times$ FARF (EQUATION I)

F = 5

$F_c = \frac{0.60 \times 92.5}{100} = .555$

FORM 4

CALCULATIONS OF "E+C"

	(a) BIN 1	(b) BIN 2	(c) BIN 3	(d) BIN 4	(e)	(f)
% BY VOLUME OF +10 MESH	2.8	17.5	31.8			49.3
POLISH VALUE		30	24			
TOTAL	~	525.0	763.2		1288.2	

WEIGHTED POLISH VALUE = $\frac{e}{f}$

WEIGHTED POLISH VALUE = $\frac{1288.3}{49.3}$ = 26.1

E+C = E2 (From TABLE VIII)

FORM 5

DETERMINATION OF SKID QUALITIES OF ASPHALTIC CONCRETE MIX

TEXTURE PARAMETERS DETERMINED FOR MIX

A = 3

B = 2

D = 2

E+C = 2

F = 5

CHART LOCATION	TEXTILE PARAMETER CONSIDERED	FRICTION WEIGHT	
		30 mph	60 mph
CHART 1	E (or E+C)	10	6
CHART 2,3 or 4 (Depending on D)	F	7	6
CHART 2,3 or 4 (Depending on D)	B	22	22
TOTAL FRICTION WEIGHT		39	34

EXAMPLE II

L.A. Wear (Abrasion) - Bin 3	= 30
Polish Value - Bin 3	= 44
- Bin 2	= 30
Insoluble Residue Test - Bin 1	= 85%
- Bin 2	= 5%
Expected ADT	= 22,500

Texas Highway Department
Construction Form No. 514 Rev. (2)

TEXAS HIGHWAY DEPARTMENT
ASPHALTIC CONCRETE SIEVE ANALYSIS WORK SHEET

County: Jacob   Highway: RM-5000   Project: F-1 (456)   Control: 1-2
Date: 4-25-73   Time: ____   Station: ____   Sampled By: ____
Spec. Item: 340   Type: D   Design No.: Trial #2

Sieve Size	Bin No. 1 (a) Weight (grams)	Total %	x 31.0 %	Bin No. 2 (b) Weight (grams)	Total %	x 22.0%	Bin No. 3 (c) Weight (grams)	Total %	x 40.0%	Bin No. 4 (d) Weight (grams)	Total %	x %	Combined Analysis % (a+b+c+d)
1¾" — ⅞"													
⅞" — ⅝"													
⅝" — ⅜"													
½" — ⅜"							59	3.7	1.5				1.5
⅜" — 4				58	7.1	1.6	1431	89.1	35.5				37.1
¼" — 10													
4 — 10	41	8.9	2.8	699	85.3	18.7	37	2.3	0.9				22.4
+ 10													61.0
10 — 40	158	34.5	10.6	34	4.2	0.9	28	1.7	0.7				12.2
40 — 80	147	32.0	9.9	7	0.9	0.2	15	0.9	0.4				10.5
80 — 200	78	17.0	5.3	11	1.3	0.3	15	0.9	0.4				6.0
Pass 200	35	7.6	2.4	10	1.2	0.3	22	1.4	0.6				3.3
Total	459 gm	100.0%	31.0 %	819 gm	100.0%	22.0 %	1607 gm	100.0%	40.0 %	gm	100.0%	%	93.0 %

PER CENT MOISTURE IN AGGREGATES IN HOT BINS

Bin No.	(a) Tare Wt. (gms.)	(b) Gross Wet Wt. (gms.)	(c) Gross Dry Wt. (gms.)	(d) Wt. Moist (gms.) b-c	(e) Dry Wt. Aggr. (gms.) c-a	% Moist. $\frac{d}{e} \times 100\%$
1						
2						
3						

Asphaltic Binder = 7.0 %
Total = 100.0%

J. S
Inspector

FORM I

TEXAS HIGHWAY DEPARTMENT

COUNTY JACOB HIGHWAY RM-5000 PROJECT F-1 (456) CONTROL 1-2

DATE 4-25-73 TIME ______ STATION ______ SAMPLED BY ______

SPEC. ITEM 340 TYPE D. DESIGN NO. Trial #2

INS. RES.		85%			5%									
POLISH VALUE					30			44						
SIEVE	SIEVE	BIN NO. 1			BIN NO. 2			BIN NO. 3			BIN NO. 4			COMBINED ANALYSIS % BY VOLUME
SIZE	SIZE	31.0	32.9		22.0	18.3		40.0	34.1					
(mm)	(in.)	% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.		% BY WEIGHT	% BY VOL.		
44.4 - 22.2	1 3/4" - 7/8"													
22.2 - 9.52	7/8" - 5/8"													
15.9 - 9.52	5/8" - 3/8"													
12.7 - 9.52	1/2" - 3/8"							3.7	1.3					1.3
9.52 - 4.76	3/8" - 4				7.1	1.3		89.1	30.3					31.6
6.35 - 2.00	1/4" - 10													
4.76 - 2.00	4 - 10	8.9	2.9		85.3	15.6		2.3	0.8					19.3
+ 2.00	+10		2.9			16.9			32.4					52.2 =D
2.00 - 0.42	10 - 40	34.5	11.4		4.2	0.8		1.7	0.6					12.8
0.42 - 0.177	40 - 80	32.0	10.5		0.9	0.2		0.9	0.3					11.0
0.177 - 0.074	80 - 200	17.0	5.6		1.3	0.2		0.9	0.3					6.1
-0.074	PASS 200	7.6	2.5		1.2	0.2		1.4	0.5					3.2
	TOTAL	100%	32.9%		100%	18.3%		100%	34.1%		%	%		

ASPHALTIC BINDER = 7.0 % BY WEIGHT = 14.7 % BY VOLUME

TOTAL 100

PREPARED BY J. S.

FORM 2

DETERMINATION OF VOLUMETRIC PERCENTAGES

	(a) PERCENT BY WEIGHT OF TOTAL MIX	(b) SPECIFIC GRAVITY OF MATERIAL	(c) $\frac{a}{b}$	(d) PERCENT BY VOLUME OF TOTAL MIX
BIN 1	31.0	2.013	15.40	32.9
BIN 2	22.0	2.568	8.57	18.3
BIN 3	40.0	2.504	15.97	34.1
BIN 4				
ASPHALT	7.0	1.020	6.87	14.7
TOTAL			46.81	100.0

FORM 3

COARSE AGGREGATE-CALCULATIONS OF "A" AND "B"

(a) AVERAGE SIEVE SIZE (mm)	SIEVE SIZE	(b) COMBINED ANALYSIS % BY VOLUME	(c) a x b	(d) WEIGHTED AVERAGE SIZE $\frac{c}{b}$
11.11	$\frac{1}{2} - \frac{3}{8}$	1.3	14.44	
7.14	$\frac{3}{8} - 4$	31.6	225.62	
4.18	$\frac{1}{4} - 10$			
3.38	4 - 10	19.3	65.23	
		52.2	305.29	5.85

$$A_u = 0.25 \times \frac{c}{b}$$

$A_u = 0.25 \times 5.85 = 1.46$ mm

$$A_c = A_u \times \text{ADJUSTMENT FACTOR (TABLE IX)}$$

$A_c = 1.46 \times 0.94 = 1.37$ A= 3

$$B_c = 0.75 \times \frac{c}{b}$$

$B_c = 0.75 \times 5.85 = 4.39$ mm B= 2

FINE AGGREGATE-CALCULATIONS OF "F

(d) AVERAGE SIEVE SIZE (mm)	SIEVE SIZE	(e) COMBINED ANALYSIS % BY VOLUME	(f) e x d	g WEIGHTED AVERAGE SIZE $\frac{f}{e}$
1.21	10-40	12.8	15.49	
0.30	40-80	11.0	3.30	
0.13	80-200	6.1	0.79	
0.04	-200	3.2	0.13	
		33.1	19.71	0.60

$F_c = \frac{f}{e} \times$ FARF (EQUATION I)

$F_c = 0.60 \times 0.925 = 0.555$

F = 5

FORM 4

CALCULATIONS OF "E÷C"

	(a) BIN 1	(b) BIN 2	(c) BIN 3	(d) BIN 4	(e)	(f)
% BY VOLUME OF +10 MESH	2.9	16.9	32.4			49.3
POLISH VALUE		30	44			
TOTAL	~	507.0	1425.6		1932.6	

$$\text{WEIGHTED POLISH VALUE} = \frac{e}{f}$$

$$\text{WEIGHTED POLISH VALUE} = \frac{1932.6}{49.3} = 39.2$$

E÷C = E 3 (From TABLE VIII)

FORM 5

DETERMINATION OF SKID QUALITIES OF ASPHALTIC CONCRETE MIX

TEXTURE PARAMETERS DETERMINED FOR MIX

A = 3

B = 2

D = 2

E+C = 3

F = 5

CHART LOCATION	TEXTILE PARAMETER CONSIDERED	FRICTION WEIGHT 30 mph	FRICTION WEIGHT 60 mph
CHART I	E (or E+C)	25	15
CHART 2,3 or 4 (Depending on D)	F	7	6
CHART 2,3 or 4 (Depending on D)	B	22	22
TOTAL FRICTION WEIGHT		54	43