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SKID TESTING IN COLORADO

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16. Abstract

Colorado began skid test investigation in 1966. A portable test device was procured, and in 1967 correlation studies were conducted comparing the portable tester's data with that obtained by the stopping distance method.

Federal participation through the Coordinator of Highway Safety enabled Colorado to purchase a truck and skid trailer in 1969. A year of mechanical modification and trial was necessary to bring the equipment into dependable operating condition, but since 1970 skid tests have been performed on every mile of the 10,000 Colorado State Highway System including the Interstate.

Assistance has been provided to District Engineers and Maintenance personnel by performing special tests on roadways in high accident areas. When remedial measures have been taken to improve slippery roadways, check tests have been run to establish whether or not the action was an improvement, and also the change in roughness (or smoothness) which results from the action.

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September 1972

TABLE OF CONTENTS

September 1972

SKID TESTING IN COLORADO

IMPLEMENTATION

The results of skid tests in Colorado have been used to establish the basis for approximately 30 miles of overlays and 'chip' seal coats on slippery roadways so far. One of the high accident areas was analyzed as to exact location and condition, and as a result it was provided with a SPRAY GRIP coating because of the extremely heavy traffic and the desire not to provide additional "dead load" on the viaduct. The accident rate appears to have dropped significantly.

One of the latest uses of skid testing has been to establish application rates for asphalt rejuvenating agents. These agents can make a roadway extremely slippery if the proper amount is not applied. A graph showing proper rates of application of one type of rejuvenating agent is included in this report.

The skid trailer can also be used to run tests for roughness of a roadway. A description of the modification necessary for this type of testing is also included in this report.

September 1972

SKID TESTING IN COLORADO

INTRODUCTION

Colorado's first investigations of highway skid resistance were initiated in the fall of 1966 utilizing a British Portable Skid Tester. The B.P.T. is a pendulum device which measures frictional resistance of a wetted surface to the passage of a wetted rubber slider. The slider, which is spring-loaded, contacts the surface along one edge of its 3 inch length. The machine can be adjusted vertically so that the length of surface that the slider transverses can be controlled. After proper adjustments are made, the pendulum and a pointer which acts from the same axis as the pendulum, are cocked in a right-hand horizontal position as shown in Figure 1. Upon release, the pendulum carries the pointers through an arc and falls away, leaving the pointer at the furthest point of the arc transversed by the pendulum. At this point a measurement is recorded from a direct scale numbered from 0 to 150 and calibrated to give readings that are 100 times the effective coefficient of friction.

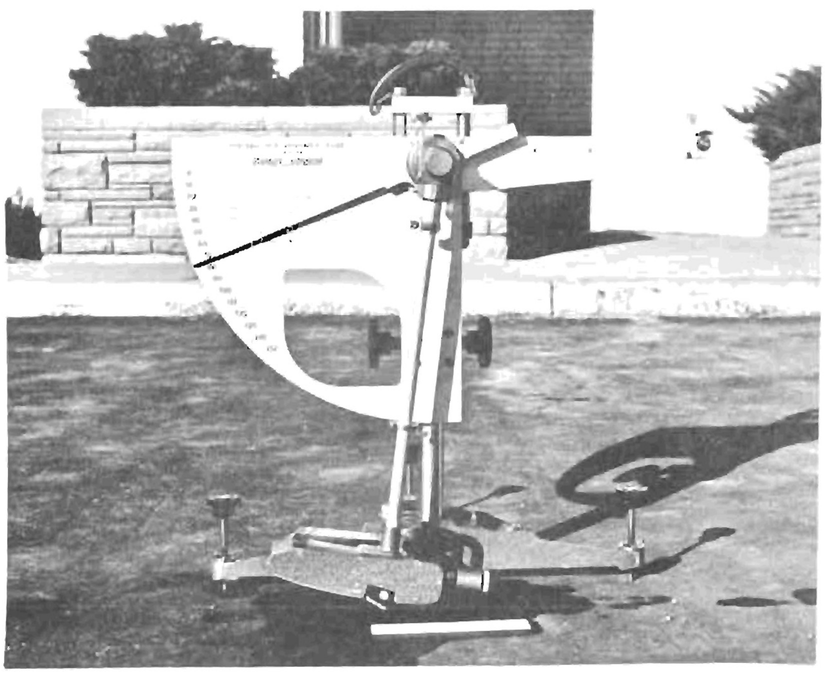


Figure 1

September 1972

Correlation of this device, with a vehicle provided and operated by the Colorado State Patrol, was conducted on test strips at Lowry Air Force Base in Denver. Test results were limited but indicated that the British Portable Tester ranked the test strips in the same order with regard to friction values as did the stopping distance method but approximately 10 percent higher.

Limited skid resistance investigations using the B.P.T. were conducted in the Denver area. Several types of surfaces were tested, ranging from bleeding asphalt to new asphaltic concrete and Portland cement concrete pavements. In general, the skid resistances on roadways and bridges in Denver at that time were quite high.

It became apparent that attempting extensive statewide skid tests, with a stationary testing device, on highways open to traffic was hazardous, time consuming, and therefore impractical. Also, it was doubtful whether a pendulum swinging at 7 mph would give a representative measure of skid resistance on wet pavements of vehicles traveling 70 mph.

In 1967 the U. S. Department of Commerce included in its proposed Highway Safety Program a provision for "conducting an inventory and evaluation of pavement coefficients for maintenance of pavement surfaces to retain adequate skid resistance." In the summer of 1967 Federal Highway Order 7-1 was issued providing procedures for obtaining Highway Safety Program funding. In April 1968 Colorado applied for a Highway Safety Project Grant to purchase a skid test vehicle and to establish a testing program for Colorado roads. The ultimate goal was to secure an inventory of Colorado road skid resistance values; and subsequently to develop a program of resurfacing or treatment in order to eliminate hazardous areas in the state's highway system as well as in local government systems.

EQUIPMENT PROCUREMENT

The application for the purchase of a skid measuring unit was approved by Federal Authorities on June 22, 1968. The Highway Department procured the Soiltest ML-350, Figure 2. The system includes a 2 ton truck carrying a water tank, a skid-test trailer, and an instrumentation system which initiates an automatic test sequence and records the results.

Instrumentation is housed in a console located in the truck cab, and includes a built-in recorder. All testing functions in the skid resistance tester are controlled by an automatic, solid-state electronic system that starts, sequentially actuates, records, and stops all test functions. In a test, the truck and trailer are driven at a speed of 40 mph and the electronic system is activated to begin the testing sequence. Water from the tank on the truck is spread on the pavement ahead of the test tire before the trailer brakes are applied. As the brakes stop the wheels, strain gauge bridges mounted on torque tubes around the rear axle electronically sense the torque imposed on the axle. The skid resistance value of the pavement is measured in terms of this torque and later converted to skid number (SN).

Figure 2

INITIAL PROBLEMS

Multiple discrepancies were discovered when the skid truck and trailer were delivered in January 1969, due to the fact that this unit was one of the first ever mass-produced. These discrepancies were resolved with the vendor. However, when the tester was put into operation a series of breakdowns followed. Problems with broken strain gauges occurred as a result of moisture condensation in the strain gauge compartment. Torque tubes had to be replaced. Of primary concern were the electric brakes which were a low-cost brake designed for intermittent use only. These were replaced with a heavy duty electric brake suitable for continuous use. The recorder timer was replaced, also.

Two recommendations can be made as a result of Colorado's experience with the equipment: (1) The 210 horsepower truck engine in the Model ML-350 does not provide the horsepower required for good automatic speed control. (2) Adequate electric or better yet air over hydraulic disc brakes are an absolute necessity for continuous braking operations.

PERFORMANCE OF WATER SYSTEM

The watering system of the Colorado unit, unlike later models which have variable speed pumps which are governed by forward speed of the vehicle, has an electrically driven constant speed pump. At 40 mph a water layer thickness of 0.022 inches is attained. This is well within the 0.020± 0.005 inches allowed by the ASTM E274-65T specification; however, the extremes of the 25 percent allowable variable are attained at about 25 mph and 58 mph. For practical purposes skid tests are limited to the 35-50 mph range and tests with this unit are made using 40 mph whenever traffic, terrain, and traffic controls permit.

CALIBRATION

Colorado considered the purchase of commercial calibration equipment for the skid trailer. However, a locally produced lever arm/weight system was developed at considerable savings. It has proved to be reliable and foolproof.

A procedure describing the calibration equipment and how to use it is shown on pages 5, 6, and 7.

Skid Trailer Calibration

Outline: The method used for calibration of a Soiltest Type Skid Trailer is basically described in the ASTM publication "Tentative Method of Test for Skid Resistance of Pavements Using a Two-Wheel Trailer", ASTM Designation: E 274-65T, issued 1965. The test utilizes a pendulum or moment arm load to create a known torque about the trailer axis. This, converted to a skid number ($\overline{SN}$), is directly related to the readings on the recording equipment.

Equipment:

Skid Resistance tester Model ML-350. (1969)

Stanford 14 inch tire wheel.

15 ft.-2¼ inch perforated steel tubing.

4 ft.-2½ inch perforated steel tubing.

2 - 5 gallon paint buckets loaded with sand (1-50 lbs., 1-60 lbs. gross weight.)

1 - 5 gallon paint bucket with variable load.

Equation:

$$T_x = F$$

$$T_y = \frac{H}{L}(T_x) = \frac{H}{L}(F)$$

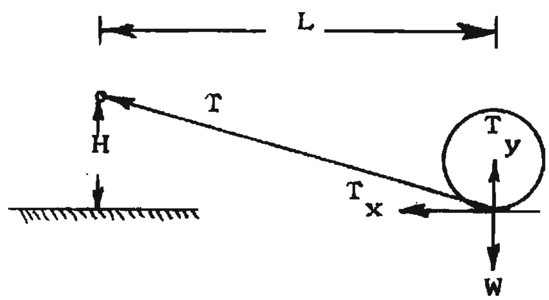
$$N = W - T_y = W - \frac{H}{L}(F)$$

$$F = u\,N;\; u = 100\,\overline{SN}$$

$$u = \frac{F}{N} = \frac{F}{W - \frac{H}{L}F}$$

$$\overline{SN} = \frac{F}{W - \frac{H}{L}F} \text{ (2 wheel test)}$$

$$\overline{SN} = \frac{2F}{W - \frac{H}{L}F} \text{ (1 wheel test)}$$



Colorado Measurements

W = 2110 lbs.

H = 19 inches

L = 116 inches

Procedure:

1) Weld a 4 foot section of 2½ inch perforated steel tubing onto the outer rim of a 14 inch tire wheel in such a manner that the tubing is aligned along the diameter. This acts as the support for the moment arm.

2) Jack up the skid trailer wheel to be calibrated. Remove the wheel with tire and place the support wheel on the axle with the tubing in the horizontal position.

September 1972

3) 3) Slide the 15 foot section of $2\frac{1}{4}$ inch tubing thru the $2\frac{1}{2}$ inch tubing to a point where 10 feet (or the distance to the truck body) is in front of the axle.

4) Balance beam about the rear axle by loading the third paint bucket located on the beam 4-5 feet behind the axle.

5) Standardize and zero skid recorder using normal procedure.

6) Lock the brake using hand brake and set wheel drive switch in the AC position. Using the 60 lb. bucket, place the load on the moment arm at one foot increments in front of the axle. Take a reading on the skid recorder at each increment and also record the loading. The last position will be 9 feet in front of the axle. Leave the 60 lb. bucket at the 9 foot location and continue the calibration with the 50 lb. bucket. The zero position on the chart recorder should be checked between each loading since this tends to change. It will be noted that the calibration loads are lower and higher than the operating loads. This extends the calibration curve to insure good data. The test is usually run 3 - 5 times to get average values. Figure 3 is the calibration curve currently being used.

7) Using the skid number ($S\bar{N}$) from the preceding page plot $S\bar{N}$ vs. chart reading for each test. This usually results in a straight line, the equation of which may be easily derived.

Example:

load = 60 lbs. at 3 feet.

$\therefore$ torque = 180 ft. - lbs. on axle.

assume distance for ℄ of axle to pavement = 1 foot.

frictional force, $(F) = \frac{180}{1} = 180$ lbs.

For one wheel Test:

$$S\bar{N} = \frac{2F}{W - \frac{H}{L}F}$$

Using Colorado trailer measurements

W = 2110 lbs.

H = 19 inches

L = 116 inches

$$S\bar{N} = \frac{2\ (180)}{2110 - \frac{19}{116}} = \frac{360}{2110 - 19} \times 100 = 17.2 \text{ use } 17$$

September 1972

8.) A transparent template (Figure 4) was produced by photographic process. This template transposed the numerical values of the curve (Figure 3) into a handy form for evaluating the Brush recorder tracings. The zero index line of the template is placed over the zero or at rest position of the recorder pen indicated on or near the left margin of the graph. The value shown is read directly from the template as "skid number."

SKID TRAILER CALIBRATION-LEFT WHEEL

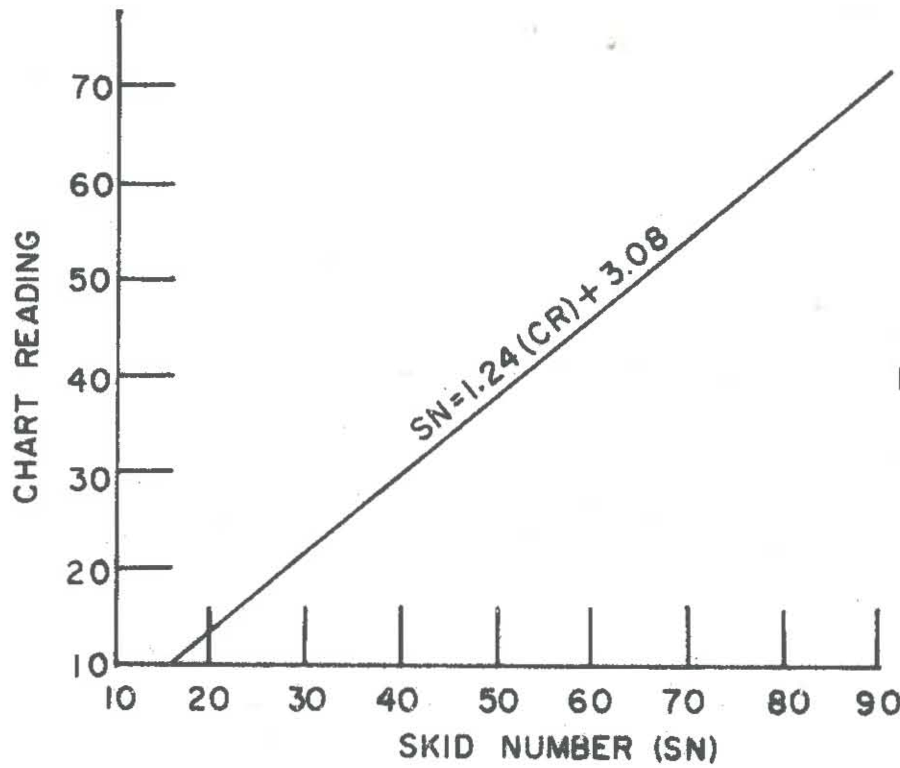


FIGURE 3

SKID NUMBER TEMPLATE-LEFT WHEEL

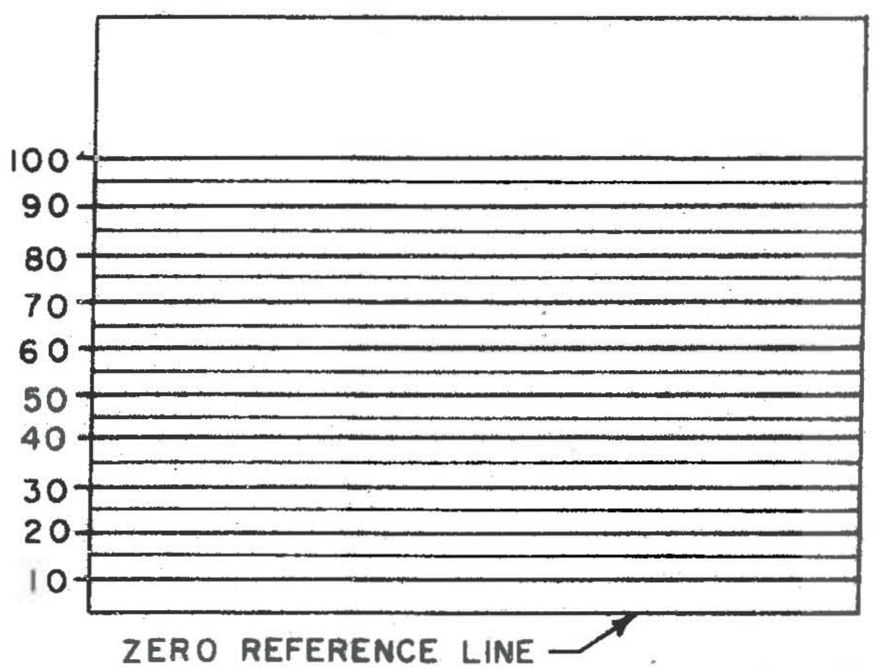


FIGURE 4

SEPTEMBER 1972

SAFETY STUDIES

In 1969 the Planning and Research Division initiated a program to measure actual skid resistance of pavements where low skid resistance was suspected or known to exist. All Engineering Districts in Colorado were requested to submit lists of roadways where there might be low skid resistance or hydroplaning conditions. In addition, the Traffic Accident Analysis Section provided a series of Three-Year Traffic Accident Reports on roadways throughout the State. All accidents involving wet conditions, skidding, or loss of control were sorted from the records and submitted. Using this information skid tests were conducted. The Districts were then requested to take corrective action to improve surface texture on any roadway where a skid number of 35 or less existed. Upon completion of the corrective action, new skid resistance data was obtained.

SPECIAL INVESTIGATIONS

The Planning and Research Division provides, on a continuing basis, skid test operations in response to requests from the Engineering Districts or local governments. Such requests usually arise after maintenance on a roadway, as a result of an accident investigation, or upon completion of a new roadway or bridge.

EFFECT OF REJUVENATING AGENTS ON SKID RESISTANCE

Skid tests have shown that excessive amounts of some asphalt rejuvenation agents can result in a very slick asphalt mat. To aid in estimating the amount of one particular agent that can be safety applied, charts have been made based on tests run on asphalt mats in various conditions of raveling located in Colorado.

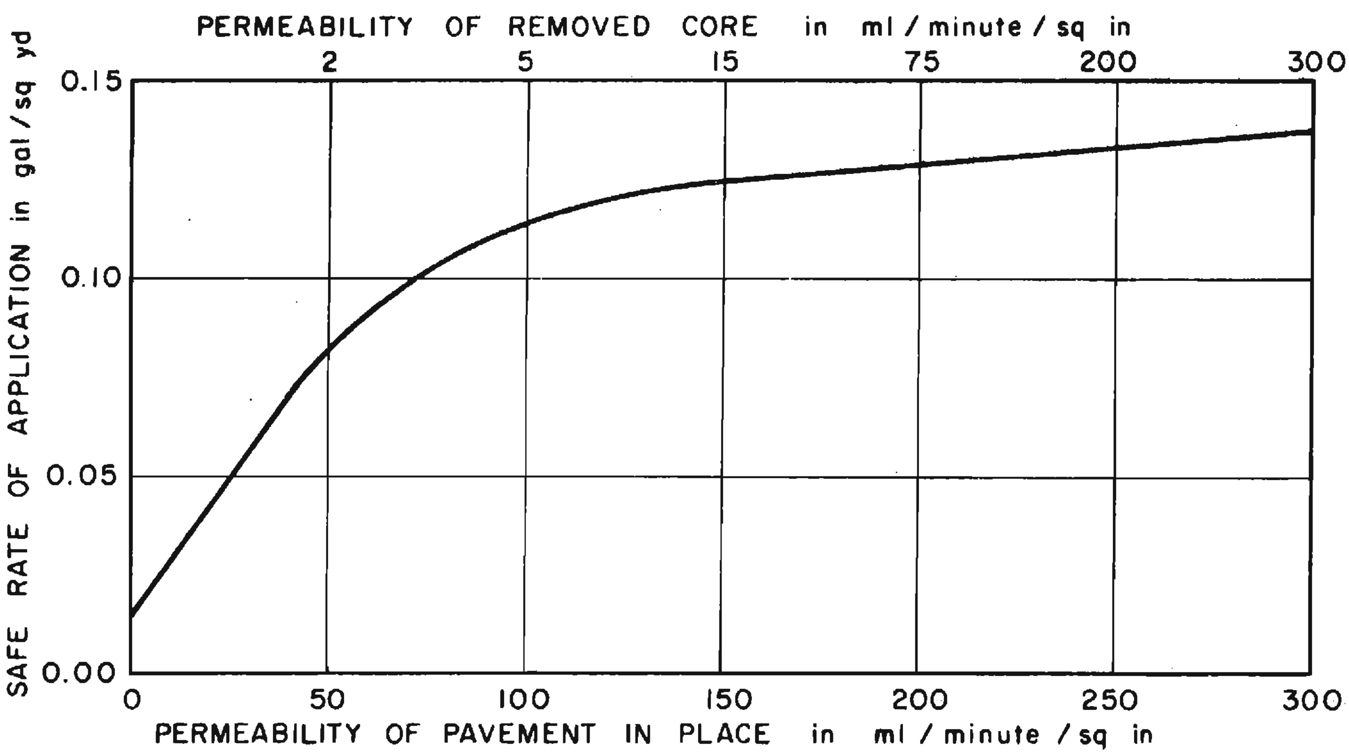
Permeability tests were run "in place" and on cores with the Soiltest AP 400A air permeability tester. Measured sections were then sprayed with what experienced engineers considered to be the proper application. Checks were made of the absorption based on color and observation in an 11 to 15 minute interval, and corrections were made for proper exact application rates.

Skid resistance values on each section were then determined with the British Portable tester which had been correlated with the Soiltest Skid Trailer traveling at 40 mph. The results are shown in the table and graph on page 10. Applications in excess of the amounts shown are likely to have skid resistance numbers below 35.

September 1972

Location	PERMEABILITY ml/Min/In² In Place	PERMEABILITY ml/Min/In² Core	Optimum Application Gal/Yd²	SKID NUMBER Before Application	SKID NUMBER After 15 Minutes	SKID NUMBER After 24 Hours
Jordan Rd DL	0	0	0.01	69	35	50
Arapahoe Road	2	0.02	0.01	69	35	50
East Jordan Rd	13	0.2	0.03	69	35	49
4201 E. Arkansas	21	0.4	0.04	56	40	50
I 25 Shoulders	43	1.0	0.07	68	44	52
East SH #30	50	2.0	0.09	85	42	64
Genesee Mtn. I 70	103	3.0	0.11	73	43	65
Chief Hosa Exit	222	60	0.13 *	80	44	71
New North I 25	400	400	0.15 *	69	48	64

* Caution should be used when applying large quantities (over 0.05 gal/yd²) on new mats. Although the rejuvenator may be absorbed without resulting in a slick surface, the mat may be softened to the point where it may be unstable in warm weather under heavy traffic.



SEPTEMBER 1972

CORRELATION

Correlation runs were made in the spring of 1970 with the Nebraska skid trailer and the Utah Mu Meter. Correlation results were good, particularly with the Nebraska equipment which is similar to Colorado's. The Nebraska Highway Department uses Soiltest's gauge to calibrate their output. The Utah Mu Meter presumably was calibrated during production in England. Figure 5a shows correlation with the Nebraska Skid trailer and Figure 5b shows correlation with the Utah Mu Meter.

STATEWIDE SURVEY FOR SUFFICIENCY AND NEEDS STUDY

The Colorado Sufficiency and Needs Study is issued every two years by the Research and Special Studies Section of the Department of Highways. The 1971 edition evaluates all non-interstate State highways in Colorado. Through this document future needs are determined using traffic as expanded to a 20 year projection. The cost to improve or reconstruct the existing roadway to meet future needs is computed.

The procedure describing the evaluation made with Colorado's skid test equipment follows. It provides data for the Safety entry and data for Present Serviceability Index (PSI) entry in the Sufficiency Rating and Needs Study. Results of the current study reveal that about 1.5% of Colorado's 10,000 miles of surfaces roads had skid numbers of 35 or lower.

The total mileage of roads with skid numbers of 35 or lower, have been or are scheduled for reconstruction, or reduced speed zones where slipperiness is not as serious. The Appendix on page 19 is a listing of these sections.

SKID TEST CORRELATIONS

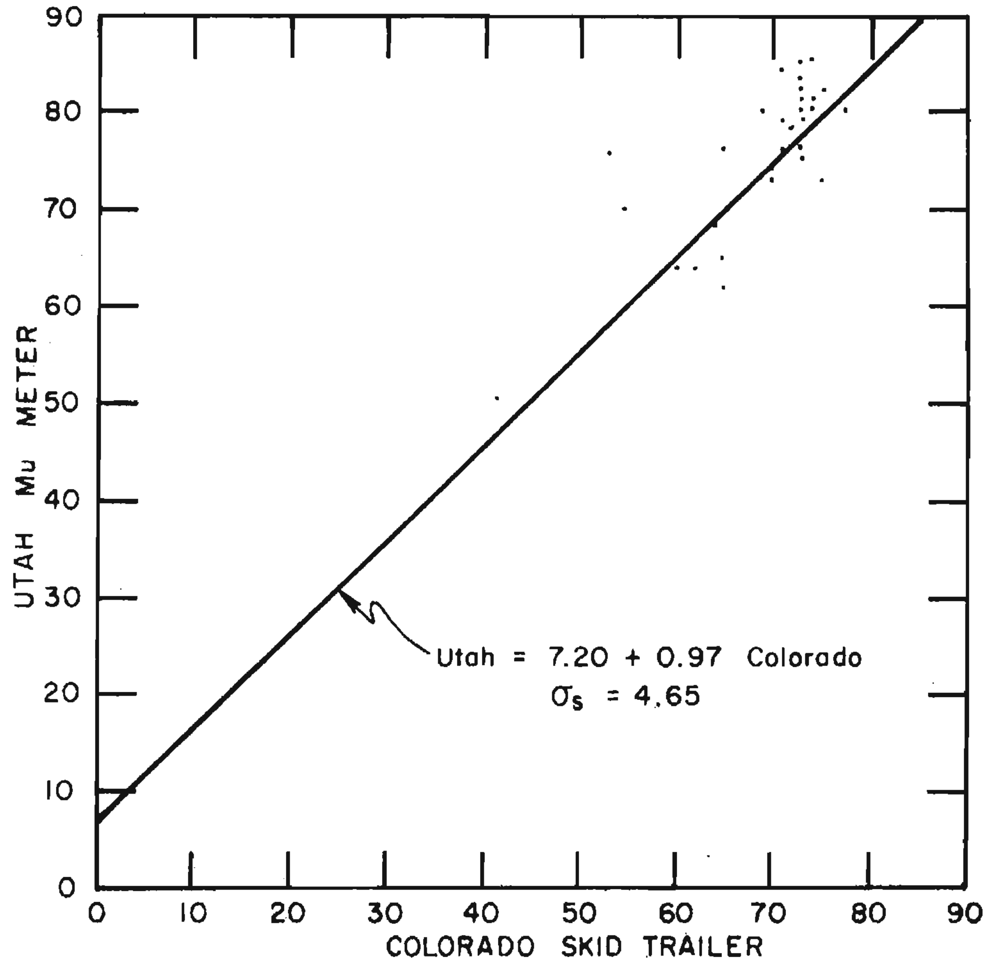


Figure 5a

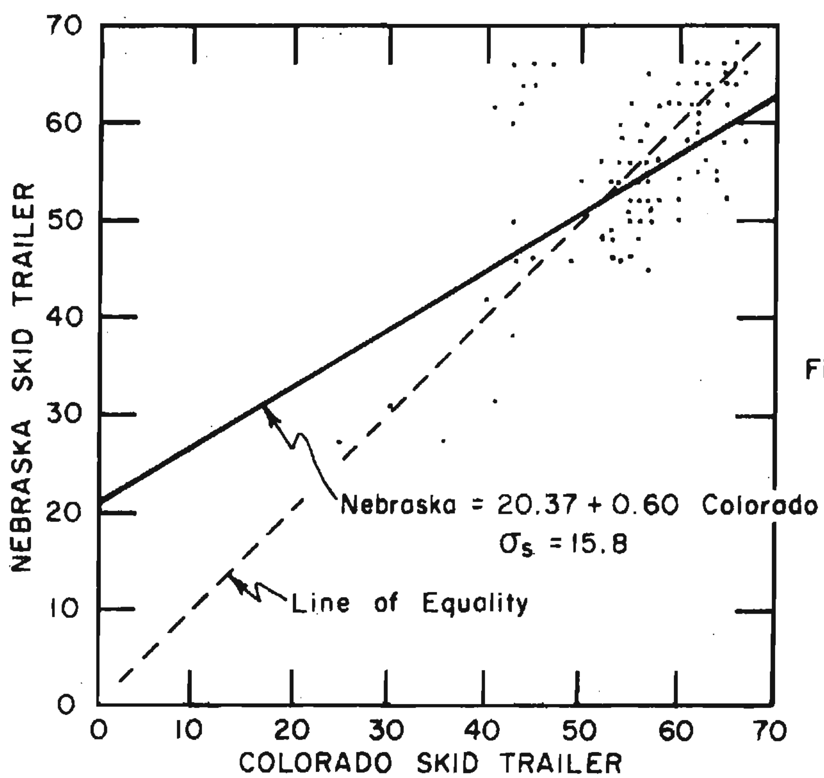


Figure 5 b

SEPTEMBER 1972

PROCEDURES FOR EVALUATION OF ROADWAYS AT 40 MPH IN COLORADO

The 1971 edition of the Sufficiency Rating and Needs Study prepared by the Research and Special Studies Section of the Colorado Division of Highways will be changed somewhat this year. In addition to the personal review of all roadways on the State Highway System, a continuous record is being made of the roughness of the surface, and an evaluation of the skid resistance is being obtained for every mile of the 10,000 mile State Highway System.

The evaluation is being made by the use of the skid trailer assembly traveling at 40 mph. Skid numbers are obtained according to the Standard ASTM procedure whereby water is sprayed in front of one of the wheels of the trailer and then the brake is locked tight for a skid. The torque on the locked wheel is measured by means of strain gauges and a signal representing the value of that torque is sent to one channel of a 2-channel recorder in the cab of the towing truck.

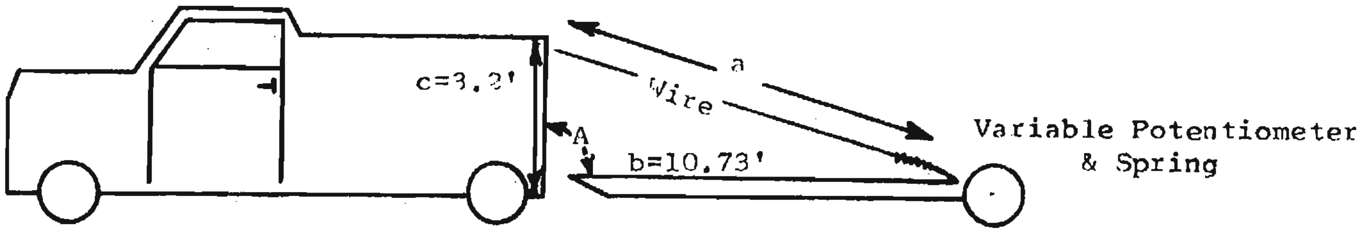
The other channel of the recorder is connected to a potentiometer attached to a cable and spring connecting an upper member of the tow truck with the chassis of the trailer. See Figures 6 and 7. The potentiometer actuates the pen of the recorder according to the change between the 2 wheels of the skid trailer and the plane established by the 4 wheels of the tow truck. Bumps over 1/2 inch high and undulations are recorded at the regular trailer speed of 40 miles per hour. The development of the formulas for the Slope Variance is shown on page 14.

The analysis of some 20,000 feet of chart paper presented a problem. What was desired was a digital readout of the graph that would correspond to the readout by the CHLOE Profilometer used by the Colorado Division of Highways. Charts were analyzed at first by making readings of the 'y' or displacement every 1/16 inch on the chart and calculating the standard deviation or slope variance. When the rolls of unanalyzed record began to accumulate, a machine was devised that would pull the record beneath a scribe attached to the old CHLOE computer. This system was a big improvement, but a more elaborate readout has now been developed based on 10 photocells which read the graph as it is run over a light. These photocells signal the old CHLOE computer and give a calculated Present Serviceability Index value which is entered in the Sufficiency Study for each subsection.

Copies of the typical graphs from the skid chart and the roughness charts are shown in Figure 8. Figures 9 and 10 show the potentiometer and readout device.

September 1972

FORUMLAS FOR SLOPE VARIANCE AND
PRESENT SERVICEABILITY INDEX
from
COLORADO'S SKID TRAILER ASSEMBLY



$a^2 = c^2 + b^2 - 2cb \text{ Cos } A$ from natural relationship of triangles.

$a^2 = 125.37 - 68.67 \text{ Cos } A$ from actual dimensions and simplification.

so Angle $A = \dfrac{\Delta a}{3.12}$ radians.

The chart recorder in the truck records vertical movements of the skid trailer wheel relative to the plane of the truck chasis as pavement irregularities are encountered.

92 Chart Units=29 computer segments=1.328 Potentiometer In. $\times \dfrac{1 \text{ ft.}}{12 \text{ in.}} \times 3.12 \dfrac{\text{Rad.}}{\text{Ft.}}$

1 Computer Segment = 0.0119 radius

Let $x = 0.0119x$

Slope Variance $= \left[\Sigma(x)^2 - N(\bar{x})^2\right] / N-1$

or $SV = 141.6 \left[\dfrac{\Sigma x^2}{N} - \left(\dfrac{\Sigma x}{N} \right)^2 \right]$

$0.015\ SV_{\text{skid trailer}} = SV_{\text{CHLOE}}$ is the experimentally determined relationship between slope variance values determined by the skid trailer and the slope variance values determined by the CHLOE Profilometer.

Depending on whether the surface is concrete or asphalt mix, the standard AASHO formulas:

$PSI_{rigid} = 5.41 - 1.8 \log (1+ SV)$ and

$PSI_{flexible} = 4.85 - 1.91 \log (1+ SV)$ are used

to obtain the PRESENT SERVICEABILITY INDEX WHEN TRAILER MOVES AT 40 MPH.

September 1972

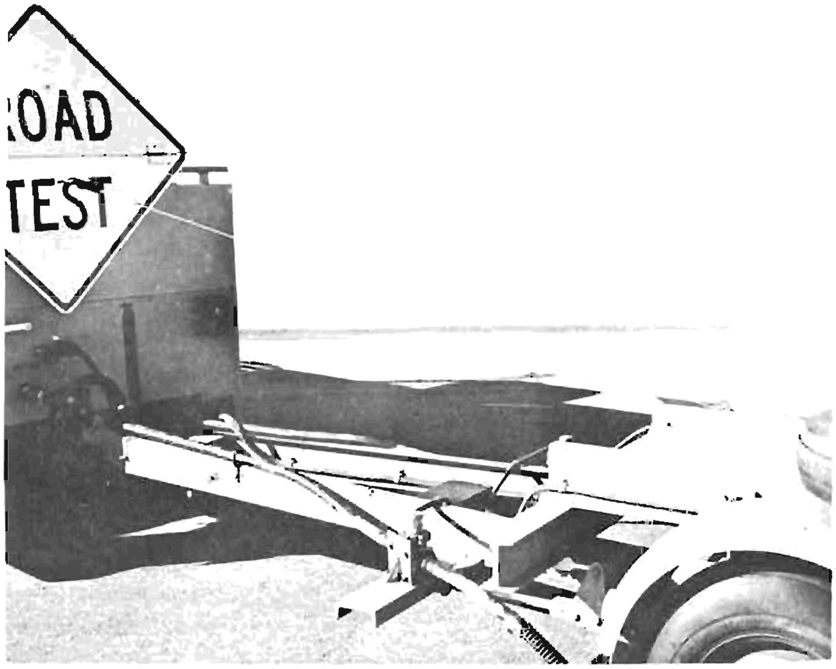


Figure 6

Cable which actuates the Potentiometer

Changes in the displacement of the trailer wheels relative to the plane of the wheels or the tow truck are registered as a change in electric current supplied to the recorder inside the cab of the tow truck.

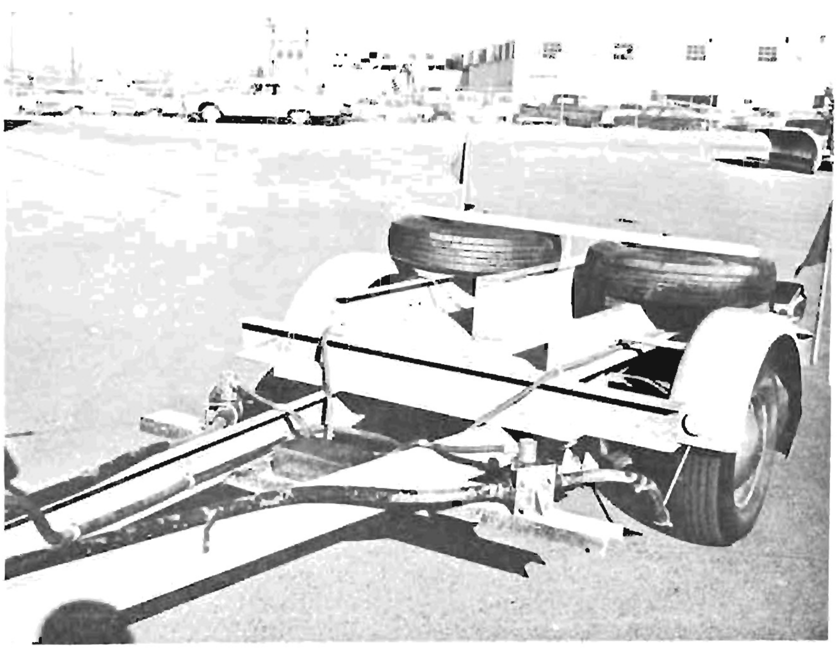


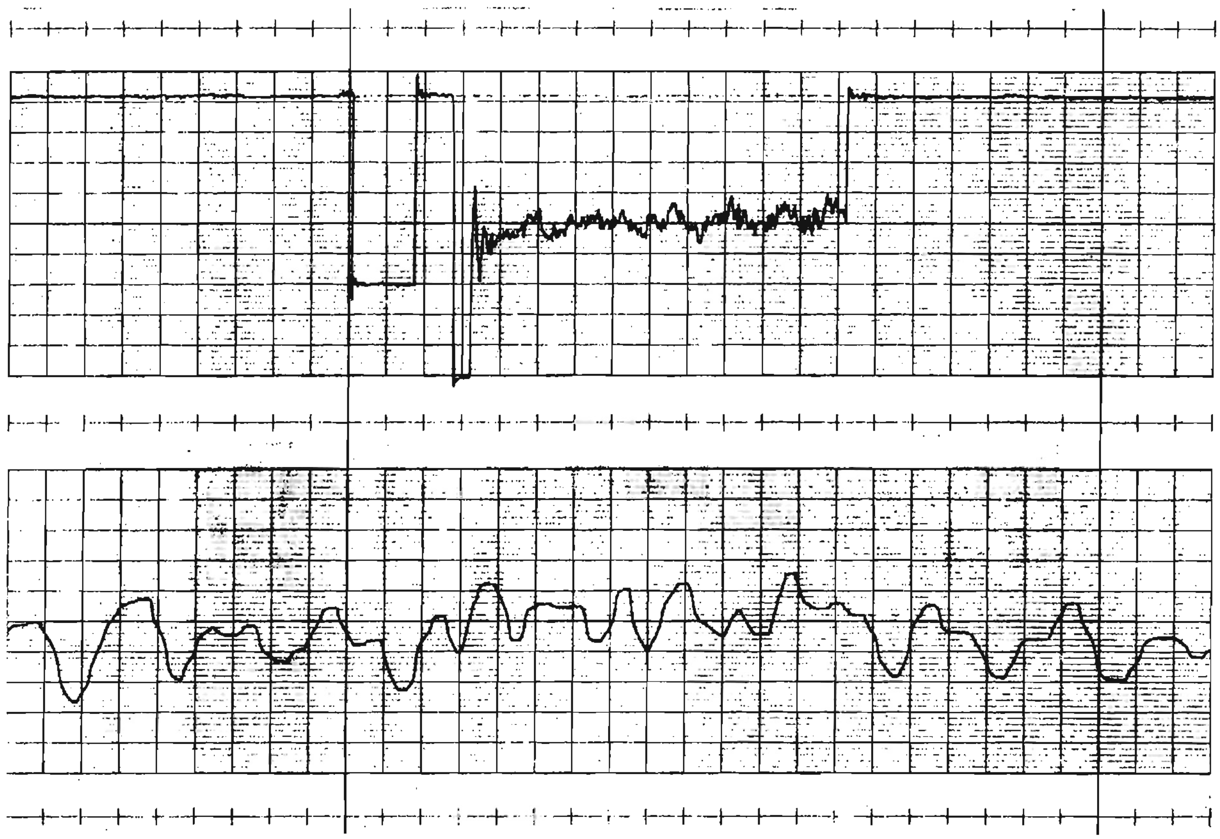
Figure 7

View of the shield in the middle of the skid trailer. Under the shield is the variable resistor.

September 1972

Typical Curve for Determination of the Skid Number

Skid Number Taken at Regular Intervals Skid Number = 55



1 Mile = 82.5 inches

Typical Curve for Smoothness

Figure 8

September 1972

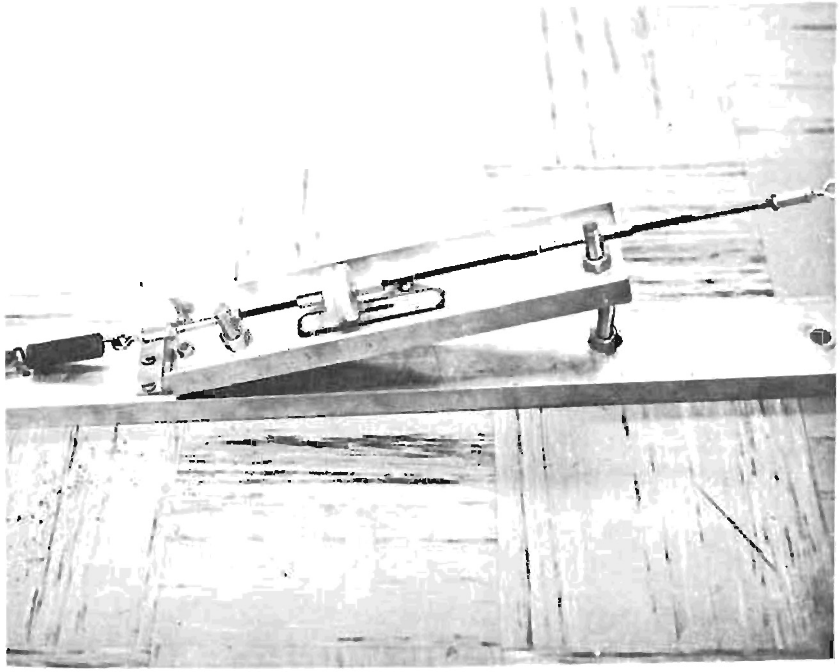


Figure 9

Close-up of the skid trailer potentiometer attachment. Cable to top of tow truck actuates the variable **resistor** and signals the recorder in the cab or the tow truck. Its function is to indicate bumps and larger undulations.

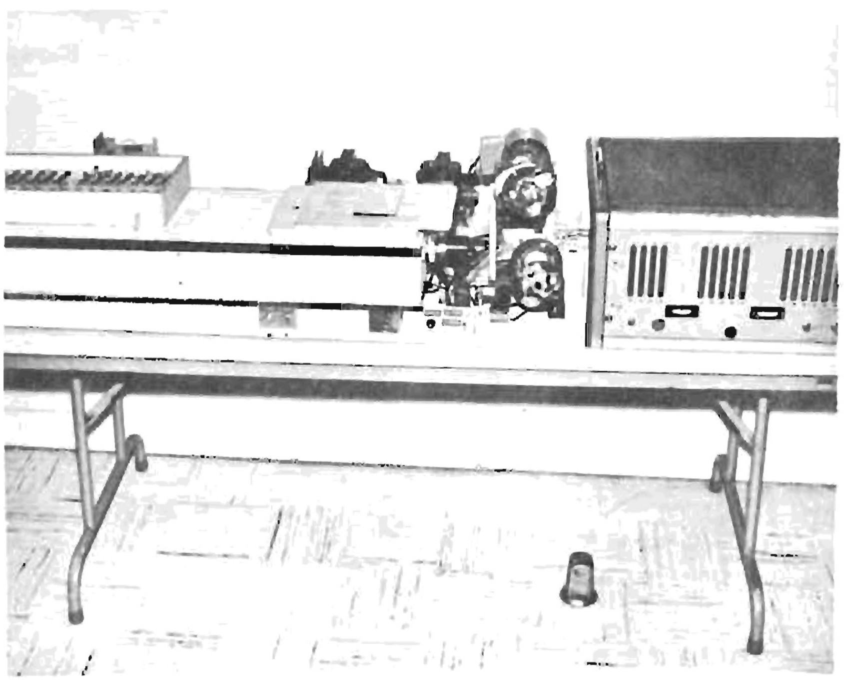


Figure 10

Chart Readout Device using light source, lens, photocells, and computer. Provides calculated Present Serviceability Index (PSI) value.

September 1972

FUTURE UTILIZATION

The Highway Safety Program in Colorado promotes regular use of the skid test equipment to check new roadways, newly maintained roadways and new overlays for skid resistance. Future accident reports involving loss of control will require skid resistance measurements in specific locations.

Local governments have made less use of the skid test equipment than was originally anticipated. The fact that it is available for use by counties and cities has been disseminated through District field office personnel but very few requests are made for the use of the skid trailer unit each year. At the annual County Meetings held in April 1972 by the State Secondary Highway Engineer, short talks and demonstrations of skid testing were made. Hopefully, interest in the use of the Skid Trailer will have been developed at these meetings, and more use will be made of this testing facility to promote safety on County and City roadways.

PROGRESS EVALUATION

The progress of determining skid numbers for roads is considered to be excellent for State Highways. All of them have been measured for skid resistance at least once and are scheduled for remeasurement in 1973. Generally, whenever a slick road is reported or observed, the trailer can be sent to determine and record a skid number for it within a few days.

Progress on measuring City and County roads is practically nil. The local governments have not asked for skid numbers even though this service is furnished at no cost to them.

September 1972

APPENDIX

LIST OF SECTIONS OF STATE HIGHWAYS HAVING SKID NUMBERS OF 35 OR LESS
(These sections were discussed with District Maintenance Superintendents and corrective actions have been planned by them.)

Route Number	Location	Miles	Skid No.	Remedial Action
24	WDL Limon to Structure No. G-22-1	1.6	27	45 mph Zone
86	WDL Kiowa to ECL Kiowa	0.5	30	35 mph Zone
71	Jct. SH 24 N for 9.1 Miles	9.1	34	Chip Seal Planned
50	1 Mile E of Rocky Ford, E for 4 Miles (Driving Lane of EB Lanes)	4.0	32	Chip Seal Planned
12	0.2 Mi E of SDL LaVeta, E for 1.1 Miles	1.1	31	Overlay
50	Jct SH 287 to ECL Lamar	0.8	25	30 mph Zone
96	WDL Boone W for 5.7 Miles	5.7	30	Chip Seal Planned
96	WDL Boone to EDL Boone	0.8	31	30 mph Zone
101	SDL Las Animas S for 0.8 Miles	0.8	32	Construction Planned
120	SDL Portland N for 2.1 Miles	2.1	20	Overlay
160	5.4 Mi from SH 100 to WDL Walsh	3.7	28	Chip Seal Planned
160	EDL Walsh E for 2.5 Miles	2.5	34	Chip Seal Planned
160	4.9 Mi from Baca Line E for 10.6 Miles	10.6	23	Overlay
196	SH 50 N for 2 Miles	2.0	18	Signed
287	E Jct. SH 96 to EDL Eads	2.3	28	Overlay Planned
13	SDL Craig to W Jct. SH 40	0.3	24	25 mph Zone
40	W Jct. SH 13 to Structure No. B-6-A	0.6	29	25 mph Zone
40	6.9 Mi W of Steamboat Springs W 2 Miles	2.0	25	Chip Seal
40	WDL Steamboat Springs W for 4 Miles	4.0	28	Construction Planned
50	NDL Olathe N for 8.4 Miles	8.4	27	Chip Seal
64	WCL Rangely to ECL Rangely	1.1	21	30 mph Zone
36	Jct. SH 66 to Jct. SH 7	10.5	28	Construction Planned

September 1972