EVALUATION OF SKID TEST AUTOMATIC DIGITAL RECORDING SYSTEM

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

The number for this report was changed post publication from 75-R5 to 75-R511 when it was discovered that the number 75-R5 was used for another report.

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways and the University of Virginia)

In Cooperation with the U. S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

July 1974
VHTRC 75-R5

SUMMARY

The Virginia skid vehicle has been equipped with a digital data recording system to provide rapid reduction of skid measurement data. It was found that five to ten minutes are required to evaluate a single measurement using the original analog strip chart system, whereas the digital results for a full day of testing can be evaluated within a matter of minutes.

The components of the recording system and the calibration and measurement procedures were examined, and the results from the digital system were studied to determine their precision and accuracy as compared to the analog system results.

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INTRODUCTION

The Virginia skid vehicle, shown in Figure 1, was designed and constructed to measure the coefficient of friction existing between a test tire and the pavement surface, which is referred to as the skid number. It consists of a truck and a two-wheeled trailer. The measurement is made when a locked trailer wheel is dragged over a wetted pavement surface at a constant speed. The vehicle has the ability to perform tests at all legal speeds within the state, and can perform more than 2500 tests per day at a rate of five per mile (1609 m) at 70 mph (31 m/s).

A Brush Instruments Corporation, Model 240, four-channel strip chart recorder was originally installed in the vehicle to provide a record of the vehicle speed and the skid-force at each test site. All other data pertaining to the test site had to be recorded manually by the instrument operator. The time required to visually read the strip chart, and file the data was from five to ten minutes for each test site. Therefore, the advantages of a fully automatic data recording system and a computerized storage and retrieval system became apparent. In order to meet the increased demand for skid-testing in the state, and the need for rapid reduction of the data, a digital data recording system was designed and installed in the skid vehicle by the Research Laboratories for the Engineering Sciences at the University of Virginia.

Figure 1. The VHRC, Model-2, skid-resistance measurement vehicle.

This report includes a description and an assessment of the analog-to-digital recording equipment and a description of the calibration and data reduction procedures used with the vehicle.

DIGITAL DATA RECORDING SYSTEM

Ample space is provided within the digital data recording system for all the data needed to describe each test site. The system will collect and record the data within 0.5 second of the end of each test. When research testing is being done, the required data and the recording sequence, to some extent, may be modified to accommodate other data entries. The only data that must remain constant in location within the recording sequence are milepost, vehicle speed, time, and the left and right wheel skid forces.

All data are converted to binary form before being transferred to a Hewlett-Packard Company, Model No. 2547A digital data coupler at the end of each test. The coupler automatically transfers the data in the proper sequence to a Tally Corporation, Model No. P-120, 8-level paper tape punch, located on the right of Figure 2, which records the data on standard 1-inch(2.54cm) wide paper tape. The data are entered on the tape using the standard IBM paper tape code, which can be changed by replacing the encoding card in the digital data coupler.

The following subsections give brief discussions of how the groups of data are obtained or generated by the digital data system. Figure 3 is a block diagram of the components and their relationships to each other.

Manually Inputted Data

All manually inputted data are entered by manipulation of 41 binary coded decimal (BCD) switches. The switches have ten positions numbered 0 to 9, and convert the base 10 data to binary form. Each switch is directly connected to the digital data coupler. The BCD switches are used to input, in code form, the general site location, (route number, county, residency, and district), date, operators, weather, air, and surface temperatures, test tire tread depth, and the current calibration. The BCD switches are located across the center of the equipment rack as shown in Figure 4.

Milepost Recording Circuit

The milepost recording circuit is designed to automatically provide to both the instrument operator and the recording system, the location of the vehicle with respect to some initial position. The system indicates the distance in increments of 0.01 mile (16 m), and may be set to subtract from or add to the initial location, which is manually entered in the distance counter by the instrument operator.

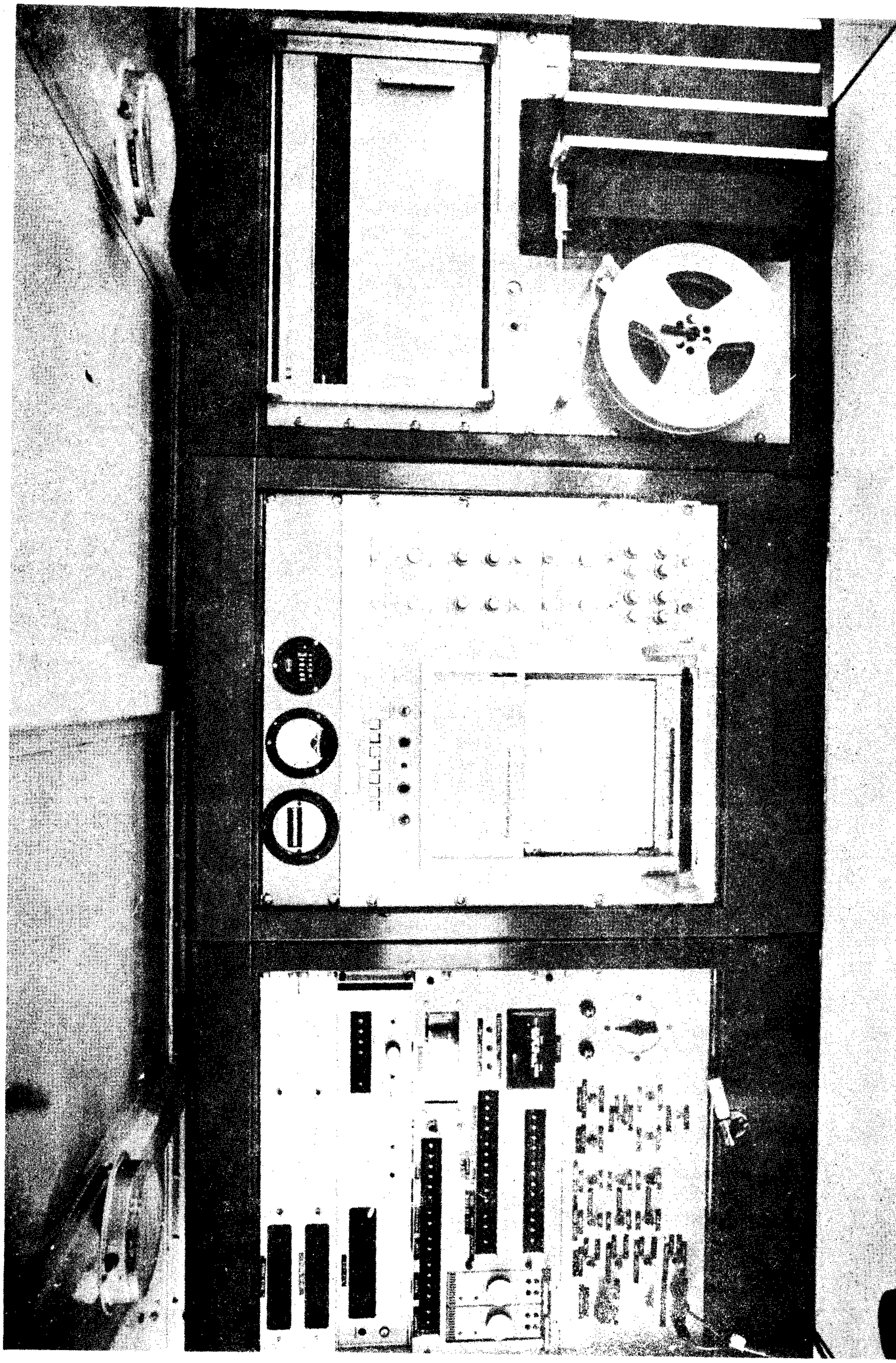

Figure 2. Skid truck instrumentation console.

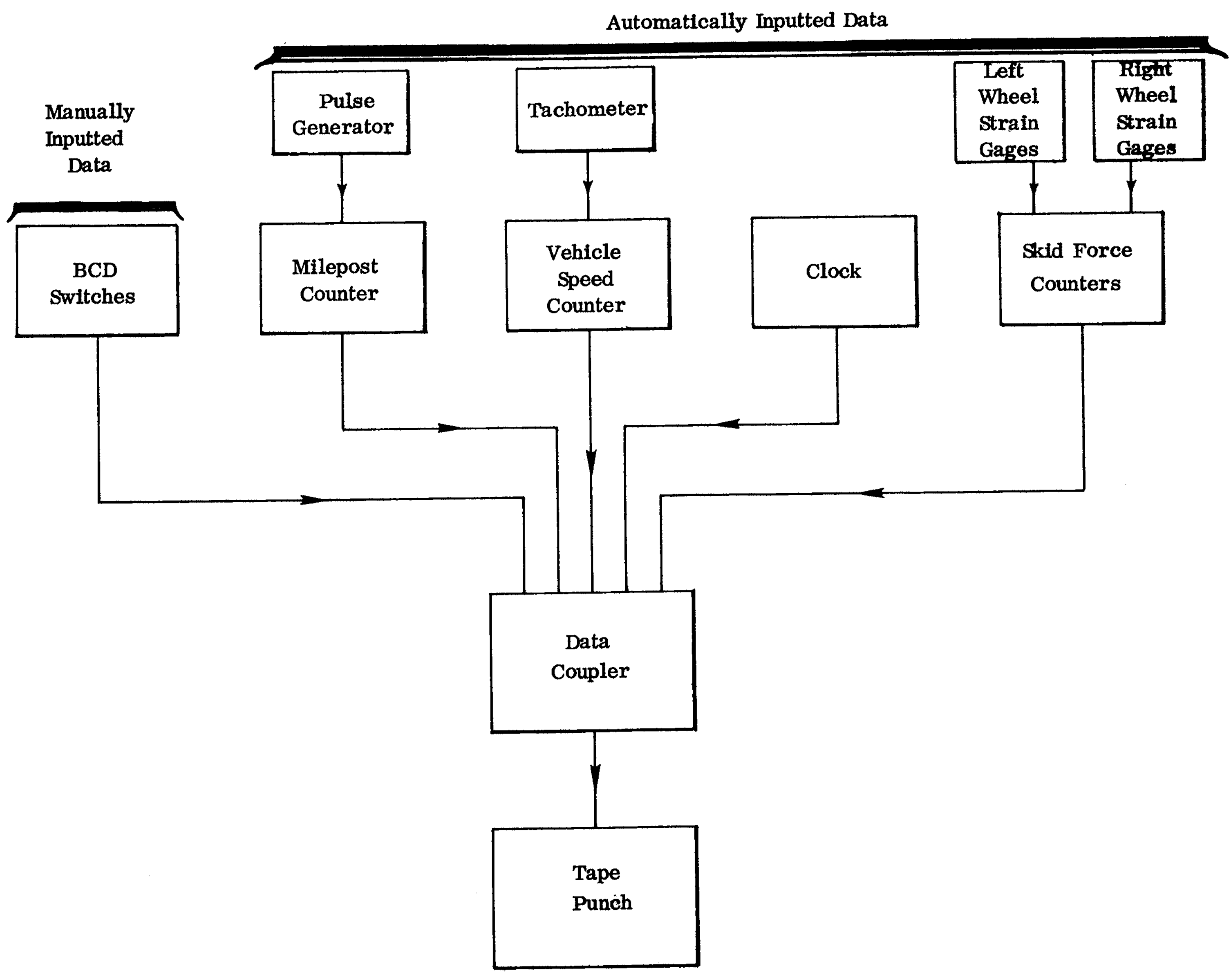

Figure 3. Block diagram of digital data recording system.

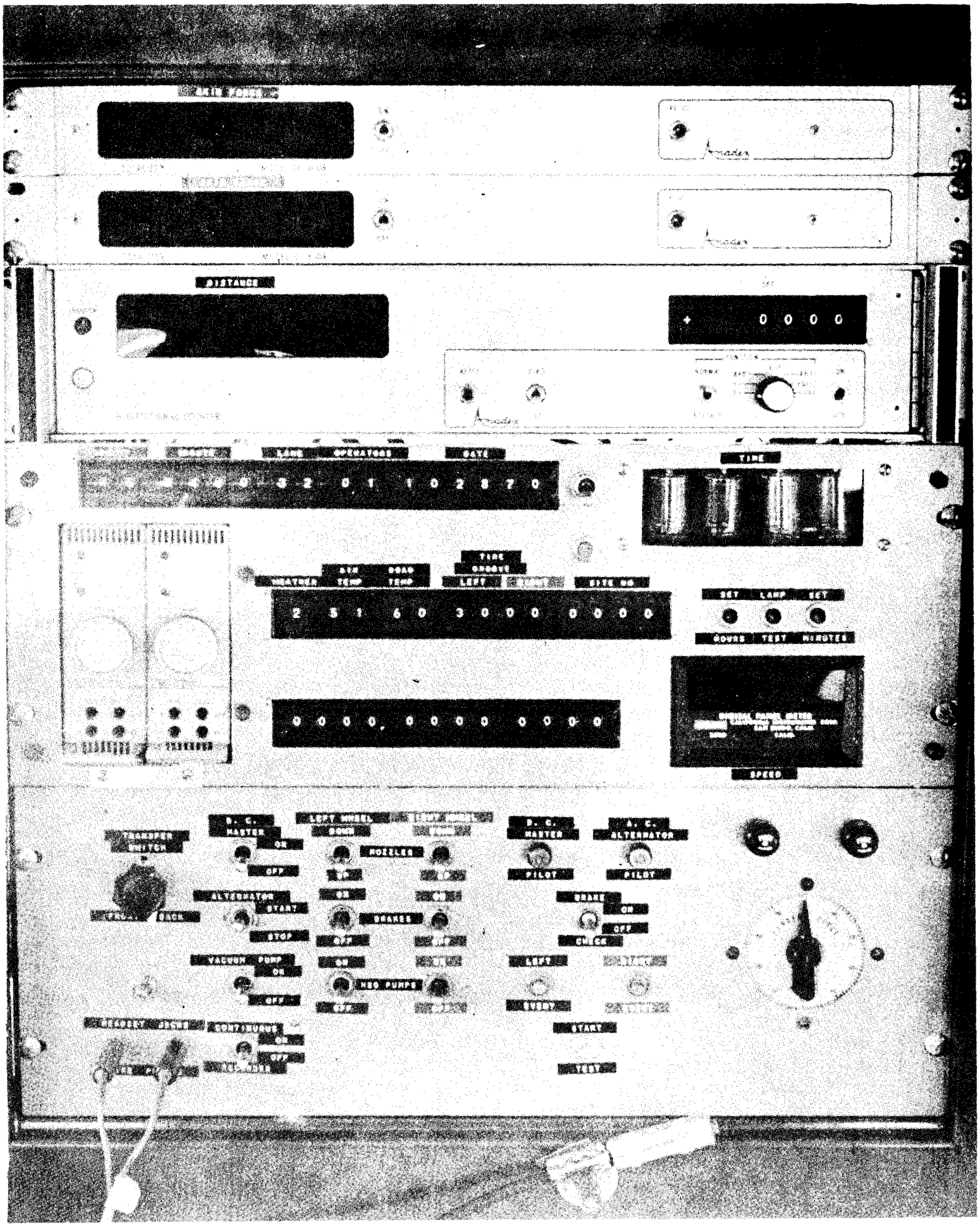

Figure 4. Instrumentation control panel.

The system operates by series of signals from a pulse generator mounted on the truck power take-off unit. These pulses are feed through a series of frequency dividers to obtain a single pulse for each 0.01 mile (16 m) traveled. This signal is then applied to an Anadex Instruments, Incorporated, No. CB-600-4R-BZ-G4-A bidirectional counter, which provides a visual readout and binary information to the data coupler in the units of miles. The milepost counter is located above the BCD switches in Figure 4.

Vehicle Speed Recording Circuit

The vehicle speed is automatically recorded and visually displayed for the instrument operator in units of miles per hour, accurate to within $\pm$ 0.1 mph (.045 m/s).

The signal is provided by a Weston Instruments, Incorporated, No. 750, direct current (DC) tachometer mounted on the power take-off of the truck. The tachometer provides a DC voltage that is proportional to the vehicle speed. This voltage is processed and applied to a California Instruments Corporation, No. 8361 digital panel meter, which is located on the lower left of the center panel in Figure 4. The vehicle speed is sent from the digital meter to the data coupler in binary form.

Time Recording Circuit

A digital clock provides signals for the time, which is recorded for each test, and for control of the measurement cycle. The basis of this clock is a 1 megahertz (MHz) quartz crystal oscillator. The signal from the oscillator is applied to a series of frequency dividers that provide the control signals and drive the 24-hour clock. This clock gives the time in units of minutes and hours, which is provided to the data coupler. The actual time is also displayed on a panel mounted indicator (upper right of center panel in Figure 4). The digital clock is set by two push button switches (below the digital clock indicator). Depressing the left switch advances the hours counter at a rate of one per second. The right switch advances the minutes counter at the same rate. The center button provides a test of the visual readouts.

Skid Force Recording Circuit

Two four-digit numbers are automatically recorded, which are proportional to the average skid force developed during the one-second measurement time required by ASTM specification E-274-65T. Both left and right wheel skid forces can be recorded.

The skid force is measured by a strain gage bridge on the wheel brake anchor pin. The signal from the strain gage is amplified by a Brush Instruments Corporation, Model No. RB-4212-00, preamplifier. The signal is then applied to the analog system circuitry and a Burr-Brown Company, Model No. 3267/12C, operational amplifier of the digital system. The output of the operational amplifier can range from 0 to 1 volt. This voltage is then converted to a frequency of constant amplitude by a Hewlet-Packard, No. 2212A Voltage-to-Frequency Converter (VCO). As the force at the strain gage changes the voltage output of the Burr-Brown amplifier varies and this results in a change in frequency. The signal is then applied to an Anadex Instruments, Incorporated, No. DC-600R-G5A events counter. The Anadex counter provides the four most significant digits of the skid force, in digital form, to the data coupler. Each force applied to the test wheel has a unique frequency output from the VCO, and therefore, a unique number as given by the Anadex counter that represents the skid force. The counters are located in the top of Figure 4. The signals from the counters are applied to the data coupler and then to the tape punch.

METHOD OF DATA REDUCTION

A degree of uncertainty is associated with skid measurements, due to pavement variability and imperfections in the measurement process and equipment. The data analyst should always be aware of sources of error and the limitations of the measuring instrument and procedure. Steps must be taken to reduce the measurement inaccuracy to an acceptable level in order that meaningful results may be obtained.

In order to maximize accuracy, a standard calibration procedure should be adhered to. The procedure used with the Virginia vehicle calibrates both the analog and digital systems simultaneously. The method used involves placing the test tire upon a movable plate. When the test wheel brake is locked a load is applied to the tire. A torque is produced on the brake assembly and axle and this is measured by the strain gage attached to the brake anchor pin. For each load applied to the test tire, a unique number, proportional to the skid force, is recorded on a strip-chart and a paper tape and is displayed on the skid force counters. The calibration, therefore, correlates the skid force with a skid number. A linear regression analysis is performed on a group of skid force values and the corresponding skid numbers to obtain a linear equation used in the paper tape evaluation.

During actual tests the required site descriptive data, in code form (see Appendix A), and the measured skid force are printed on paper tape. The skid force is also simultaneously recorded by the analog system on a strip chart.

The paper tape is decoded by a computer program designed to convert the skid force obtained during the test to its corresponding skid number using the linear regression equation. The computer program was developed by the Research Council's Data Section and is described in Appendix B. The program provides a printout of all site descriptive data and the site's skid number. A typical printout is shown in Figure 5. The program and printout may be easily modified to provide predicted stopping distance numbers or information necessary for special research projects.

SYSTEM CORRELATION AND ACCURACY

To determine the performance of the digital recording system approximately 800 tests were run and simultaneously recorded by the analog and digital systems. The digital and analog results for individual tests were compared to determine any differences. The results from each test series, that is any group of tests performed on the pavement under constant conditions, were analyzed to determine the repeatability or precision of the data. Similar test series were also compared to check for any instrumentation drift.

Appendix C contains the average skid numbers, the standard deviations, and the mean squares for both the digital and analog results, as well as the average difference

VIRGINIA HIGHWAY RESEARCH COUNCIL

SKID DATA SYSTEM

SPECIAL-TEST-IDENTIFICATION 0

COUNTY 7 ROUTE NO. 81 MONTH 12 DAY 6 YEAR 73 WEATHER 1 DRIVER 0 DISTRICT 8 RESIDENCY 53 CITY/TOWN 0

AIR TEMPERATURE 14 SURFACE TEMPERATURE 10 LEFT TIRE GROOVE 30 RIGHT TIRE GROOVE 0 INSTRUMENT OPER. 9 CALIBRATION 350

TRAFFIC LANE	TRAFFIC DIRECTION	DATA TYPE	HOUR	MINUTE	VEHICLE SPEED	MILEPOST	Y	SPECIAL-TEST-IDENTIFICATION
2	2	0	14	38	40.2	9.55	77	0
2	2	0	14	38	39.6	9.30	76	0
2	2	0	14	38	38.9	9.07	74	0
2	2	0	14	39	40.0	8.90	76	0
2	2	0	14	39	39.0	8.70	75	0
2	2	0	14	39	39.4	8.50	63	0
2	2	0	14	40	40.2	8.30	62	0
2	2	0	14	40	40.0	8.10	67	0
2	2	0	14	40	40.0	7.90	65	0
2	2	0	14	40	40.7	7.70	67	0
1	1	0	14	45	38.9	7.70	71	0
1	1	0	14	45	39.6	7.89	71	0
1	1	0	14	45	41.1	8.10	68	0
1	1	0	14	45	40.5	8.30	67	0
1	1	0	14	46	40.2	8.50	67	0
1	1	0	14	46	39.6	8.70	72	0
1	1	0	14	46	40.3	8.90	70	0
1	1	0	14	47	40.3	9.12	75	0
1	1	0	14	47	40.6	9.30	74	0
1	1	0	14	47	39.1	9.50	70	0

Figure 5. Typical computer printout.

TABLE 1

DIFFERENCES BETWEEN SYSTEMS GROUPED ACCORDING TO MEASURED SKID NUMBER

of Tests In Range	Analog SN Range*	Digital SN Range*	Differences	Minimum Individual Differences	Maximum Individual Differences
50	26 - 30	35 -39	7.6	3	16
130	31 - 35	41 - 48	9.5	3	17
100	36 - 40	43 - 49	7.9	-2	15
210	41 - 45	46 - 58	9.4	-6	18
120	46 - 50	50 - 62	9.3	-1	18
30	51 - 55	56 - 66	7.7	0	18
60	56 - 60	60 - 64	5.1	-1	14

* Average range is found from test series.

between the two systems for each test series. These series were randomly chosen from various tests performed under differing speed, pavement, and water depth conditions.

The average differences were grouped according to average analog skid number to determine if the differences were dependent on the magnitude of the skid numbers. Table 1 shows these data. Upon examination of the data in Appendix C and Table 1, it may be seen that the digital results are consistently higher than the analog results by 8.6 skid numbers, with no dependence on the measured skid number. This difference poses no problem since it does not affect the realiability of the digital system. The fact that the digital results are higher than the analog results in no way affects the ability of the digital system to study relative skid numbers or to generate predicted stopping distances.

The repeatability of the two systems is given by the standard deviation, which is given for each test series in Appendix C. A standard deviation for all tests was found from the total mean square for both systems. This was found to be 3.45 for the digital system and 3.26 for the analog system. These two numbers are such that it may be stated that the two systems are equally precise.

Apparent instrumentation drift was noted in results from both systems on several occasions during the testing period. It was observed that this drift occurred mostly during the summer months, when high temperatures are encountered in the instrumentation compartment of the skid truck. Table 2 shows a set of data in which instrumentation drift was prevalent. On this day the temperature rose to well above 110°F (43.3°C) in the skid truck. These data were gathered before the measurement procedure was finalized, therefore the average difference is lower than 8.6. As shown in Table 2, and illustrated graphically in Figure 6, the average difference for each site becomes greater as the temperature rises.

TABLE 2

DATA WITH APPARENT INSTRUMENTATION DRIFT

Site No.	Air * Temp.	Average SN + Digital	Average SN + Analog	Difference
1	85°F	53.7	55	-1.30
2	86	47.2	46.4	0.80
3	87	46.4	41.4	5.0
4	88	42.9	38.1	4.8
5	89	40.2	33.1	7.1
6	91	67.6	63.4	4.2
7	92	60.9	55.0	5.9
8	93	55.8	49.0	6.8
9	94	51.1	44.0	7.1
10	95	46.8	39.3	7.5

*Values extrapolated from the measured values. The temperatures in the skid truck are assumed to be 20°C higher.

+Averages of 14 tests.

$^{\circ}C = (^{\circ}F-32) \times \frac{5}{9}$

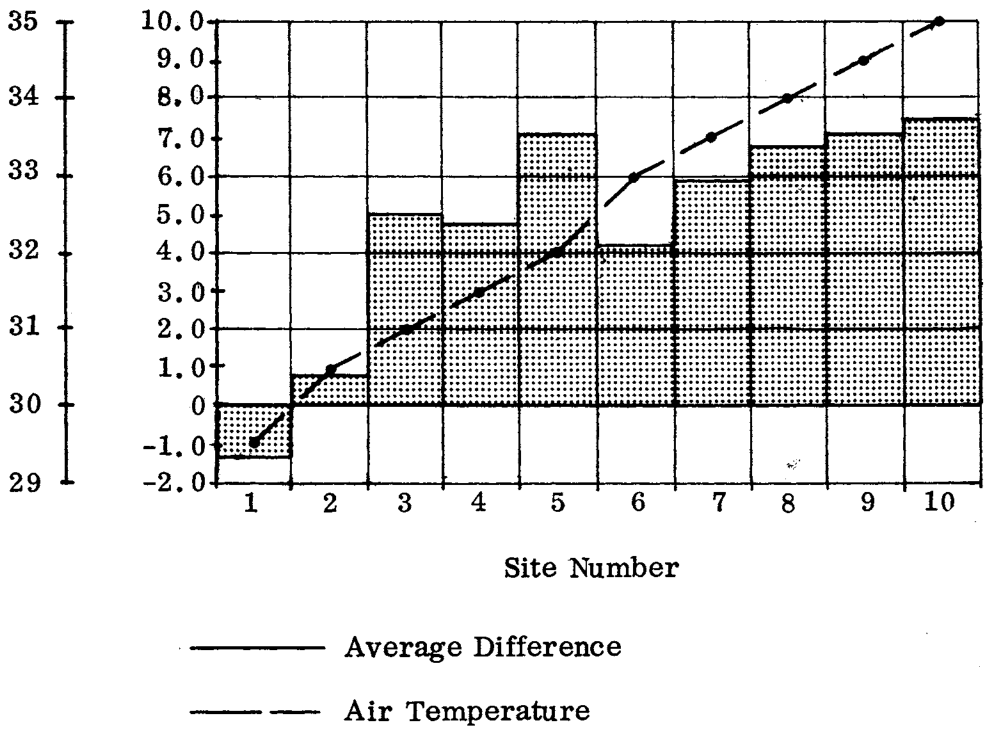

Figure 6. Dependence of instrumentation drift with temperature.

It was found that the digital system is very sensitive to the strain gage amplifier balance settings. The digital and analog systems have to be balanced simultaneously using the strip chart recorder. Obtaining accurate data requires rebalancing both systems several times during a day of testing.

EQUIPMENT PERFORMANCE

The equipment of the digital data recording system performed as expected with only a few minor problems being encountered. The only exception was the paper punch, which malfunctioned soon after its installation and had to be returned to the factory for repairs. Occasionally a hole will be omitted or mispunched on the tape; however, this is not considered serious, as less than 2 percent of all records have been found to be faulty.

The skid force, milepost, and timing circuits have remained exceptionally stable and trouble free since the beginning of this project.

A problem with the paper tape occurred during the summer months due to the high temperatures encountered in the truck. When the tape was exposed to high temperatures it would become translucent due to its high oil content. The computer system used to evaluate the skid data employs an optical reader and this would not perform properly because of the excessive light coming through the tape. This problem was corrected by using tape with a lower oil content, that appears to be immune to the high temperatures and results in "cleaner" punched holes, thus lessening the previously mentioned problem.

CONCLUSIONS

The digital data recording system greatly decreases the time required to reduce skid measurement data to a useful form. It was found that to obtain the most accurate data, the precautions and procedures given below should be observed:

1. A correction factor of 8.6 skid numbers should be subtracted within the computer program from the digital data in order to agree with the analog system.

2. The instrument operator should regularly check the base line set on the strip chart to see that it is at the proper location. If any drift is detected, the strain gage preamplifiers should be rebalanced.

3. When high temperatures are encountered in the skid truck, operations should be avoided to eliminate possible instrumentation drift.

The digital system performs as it was designed to, and is an asset to the Virginia skid resistance measurement vehicle. Any data analysis or plots may be made by an addition to the computer program, and the desired information obtained in a matter of minutes.

RECOMMENDATIONS

In light of the performance of the digital data recording system, it is recommended that it be placed in full use in order to gain its benefits. The computer program should include the 8.6 skid number correction factor. The performance of the digital system should be periodically checked. It is recommended that this be done by simultaneously recording all control test loop data by both systems and checking differences. If the difference is $\pm$ 3.0 skid numbers the digital system's performance is acceptable. If the difference does not meet the requirements, subsequent data should be simultaneously recorded and the system's performance redetermined.

It is also recommended that the skid truck be air-conditioned in order to reduce problems with instrumentation drift and add to the comfort of the operators during the summer months. If the truck is not air-conditioned, it is suggested that no testing be performed when the temperature inside the vehicle exceeds 100°F (37.8°C).

A study of the measurement and calibration procedures is also recommended. It is felt that better measurement practices would enhance the accuracy and precision of both systems.

ACKNOWLEDGEMENTS

The author thanks all those persons who gave assistance on this project. Special thanks are due Charles W. Payne and David W. Hill, the skid trailer instrument operators, Sarah A. Kelly, who developed the computer program, and S. N. Runkle, who assisted with the data analysis, for their assistance and suggestions during the project and their patience during the many changes made in the system software.

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APPENDIX A

VIRGINIA HIGHWAY RESEARCH COUNCIL
SKID RESISTANCE MEASUREMENT VEHICLE
DIGITAL DATA RECORDING SYSTEM CODE MANUAL

by

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(A Cooperative Organization Sponsored Jointly by the Virginia
Department of Highways and the University of Virginia)

Charlottesville, Virginia

April 1974

INTRODUCTION

The purpose of this manual is to provide information as to the proper codes to be used to input data into the digital data recording system on the Virginia Highway Research Council's skid trailer. The codes provided should encompass all situations which may arise, and are consistent with those used in other data systems employed by the Virginia Department of Highways. The codes and recording sequence are intended for testing accident sites and for survey testing, and may be extensively modified for research projects where the ability to record special data is required.

The codes are in the sequence in which they are to be recorded, and a brief description of the data required is given for each data set that must be inputted. Also indicated are items of data which are automatically entered for each skid test.

County (columns 1-2)

The appropriate two digit number for the county as shown below should be placed in columns 1 and 2.

County	Code	County	Code
Arlington	00	Greene	39
Accomac	01	Greensville	40
Albemarle	02	Halifax	41
Alleghany	03	Hanover	42
Amelia	04	Henrico	43
Amherst	05	Henry	44
Appomattox	06	Highland	45
Augusta	07	Isle of Wight	46
Bath	08	James City	47
Bedford	09	King George	48
Bland	10	King & Queen	49
Botetourt	11	King William	50
Brunswick	12	Lancaster	51
Buchanan	13	Lee	52
Buckingham	14	Loudoun	53
Campbell	15	Louisa	54
Caroline	16	Lunenburg	55
Carroll	17	Madison	56
Charles City	18	Mathews	57
Charlotte	19	Mecklenburg	58
Chesterfield	20	Middlesex	59
Clarke	21	Montgomery	60
Craig	22	Nansemond	61
Culpeper	23	Nelson	62
Cumberland	24	New Kent	63
Dickenson	25	Northampton	65
Dinwiddie	26	Northumberland	66
Essex	28	Nottoway	67
Fairfax	29	Orange	68
Fauquier	30	Page	69
Floyd	31	Patrick	70
Fluvanna	32	Pittsylvania	71
Franklin	33	Powhatan	72
Frederick	34	Prince Edward	73
Giles	35	Prince George	74

County	Code	County	Code
Gloucester	36	Prince William	76
Goochland	37	Pulaski	77
Grayson	38	Rappahannock	78
Richmond	79	Stafford	89
Roanoke	80	Surry	90
Rockbridge	81	Sussex	91
Rockingham	82	Tazewell	92
Russell	83	Warren	93
Scott	84	Washington	95
Shenandoah	85	Westmoreland	96
Smyth	86	Wise	97
Southampton	87	Wythe	98
Spotsylvania	88	York	99

Note: For the cities shown below use the county codes indicated.

City	County Code
Virginia Beach	75
Hampton	27
Newport News	94
Norfolk	64
Portsmouth	64
Chesapeake	64

Route (columns 3-6)

The county numbers shown in the graphic log should be recorded in columns 4, 5, and 6. When two routes are the same, i.e., overlapping routes, code the predominate route as shown in the graphic log.

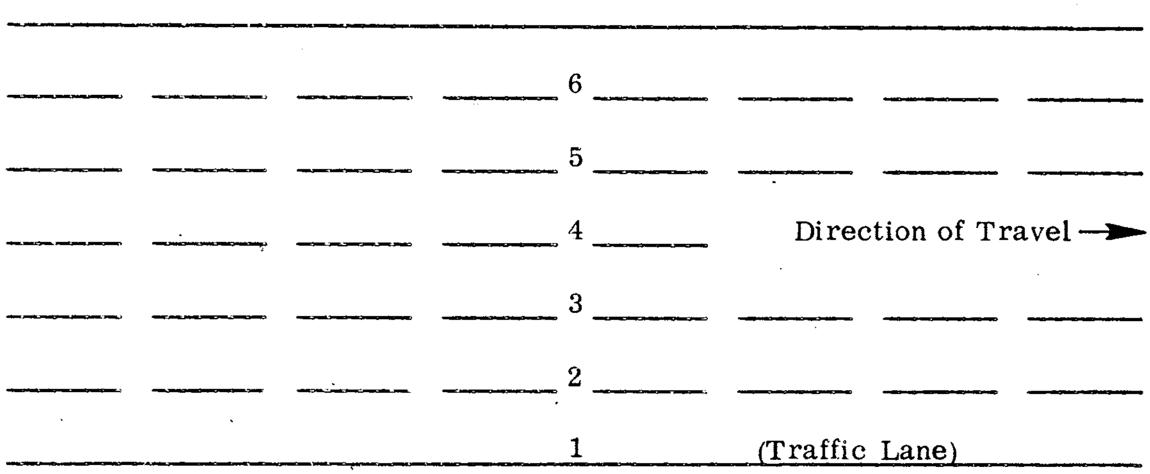
Prefixes for special routes should be coded in column 3 as shown below.

Route Type	Code
Alternate	1
Bypass	2
Commercial (Business)	3
Alternate Y	4
Z	5
Interstate	6

When testing the control loop code 9 in column 3, and code the site number in columns 4-6. Thus, site 1 on the control loop should be coded 9001.

Traffic Lane (column 7)

When there is more than one lane of travel in any given direction, code the lane tested as shown in the diagram below.



For express lanes or the middle lane of a three lane highway (lanes in which the direction of travel may change periodically) code a 5 in the Direction column and the appropriate lane number in the Lane column facing away from the zero milepoint.

When testing on a two-lane highway, code the lane as 1 with the appropriate direction code.

Traffic Direction (column 8)

The digit, as shown below, representing the direction of travel should be placed in column 8.

Direction	Code
North	1
South	2
East	3
West	4
Express Lanes	5

Operators (columns 9-10)

Column 9 should contain a code for the driver, and column 10 should contain a code for the test data recorder. Codes are shown below for individuals most likely to be involved in skid testing.

Person	Code
Hill	0
Payne	1
Blackwell	2
Huckstep	3
Breeden	4
Henderson	5
Sturgel	6
Miscellaneous	9

Date of Test (columns 11-16)

Columns 11 and 12 should contain the month coded as shown below. Columns 13 and 14 should contain the day of the month, and columns 15 and 16 should contain the last two digits of the year.

Month	Code
January	01
February	02
March	03
April	04
May	05
June	06
July	07
August	08
September	09
October	10
November	11
December	12

Examples	Date of Completion	Coded
	March 1, 1972	030172
	November 25, 1972	112572

Time (columns 17-20)

The time of the test is automatically coded in columns 17-20.

End of Word Code (column 21)

An end of word code is automatically entered in column 21 for each skid test.

Weather (column 22)

A one digit code as shown below should be used to indicate the weather conditions during the testing period.

Weather Condition	Code
Unspecified	0
Clear	1
Cloudy	2
Foggy	3
Misting	4
Raining	5
Snowing	6
Sleeting	7
Smoke-Dust	8

Air Temperature (columns 23-24)

Code air temperature in degrees centigrade (nearest degree) in columns 23 and 24.

Surface Temperature (columns 25-26)

Code surface temperature in degree centigrade (nearest degree) in columns 25 and 26.

Left Tire Tread Depth (columns 27-28)

Code the average left wheel tread depth correct to the nearest one-hundredth inch in columns 27 and 28.

Right Tire Tread Depth (columns 29-30)

Code the average right wheel tread depth correct to the nearest one-hundredth inch in columns 29 and 30.

Test Code (column 31)

In order to reject any faulty records when evaluating the punched tape, the digit 4 should be inputted in column 31. The test code will change only at the beginning of a new year, when it will become the last digit in the year.

City/Town (columns 32-34)

If the testing occurs within a city or town or on a commercial route, the appropriate code, as indicated below, should be recorded in columns 56 to 58, otherwise these columns all should contain zero. When testing on a state maintained noncommercial route within a city the county should be inputted.

District	County	Route*	City/Town	Code
Bristol	Wise	C023	Pound	285
	Wise	C023	Wise	329
	Scott	C023	Gate City	221
	Scott	C058	Gate City	221
	Washington	C091	Glade Spring	222
	Scott	C421	Gate City	221
	Tazewell	C460	Cedar Bluff	184
	Tazewell	C460	Richlands	148
Salem	Franklin	C220	Rocky Mount	157
	Henry	C220	Ridgeway	290
	Bedford	C297	Bedford	141
	Bedford	C460	Bedford	141
	Montgomery	C460	Christiansburg	154
	Montgomery	C460	Blacksburg	150

District	County	Route*	City/Town	Code
Lynchburg	Charlotte	C015	Keysville	248
	Pittsylvania	C029	Chatham	187
	Pittsylvania	C029	Danville	108
	Campbell	C029	Lynchburg	118
	Amherst	C029	Amherst	163
	Nelson	C029	Lovingston	
	Charlotte	C360	Keysville	248
	Appomattox	C460	Pamplin City	277
	Prince Edward	C460	Pamplin City	277
Richmond	Brunswick	C058	Lawrenceville	251
	Hanover	C360	Mechanicsville	
	Amelia	C360	Amelia	
	Nottoway	C360	Burkeville	181
	Nottoway	C460	Burkeville	181
Suffolk	Accomac	C013	Accomac, Onley	160
	Northampton	C013	Eastville	214
	Northampton	C013	Cheriton	188
	Northampton	C013	Exmore	217
		C013	Virginia Beach, Norfolk, and Chesapeake	122
		C017	Portsmouth	124
		C058	Virginia Beach	134
Fredericksburg	Spotsylvania	C001	Fredericksburg	111
	Spotsylvania	C017	Fredericksburg	111
	Stafford	C017	Fredericksburg	111
	Caroline	C301	Bowling Green	171
Culpeper	Loudoun	C015	Leesburg	253
	Fauquier	C015	Warrenton	156
	Culpeper	C015	Culpeper	204
	Orange	C020	Orange	275
	Albemarle	C029	Charlottesville	104
	Madison	C029	Madison	256
	Culpeper	C029	Culpeper	204
	Fauquier	C211	Warrenton	156
	Rappahannock	C211	Washington	322
	Albemarle	C250	Charlottesville	104
	Rappahannock	C522	Washington	322

District	County	Route*	City/Town	Code
Staunton	Augusta	C011	Staunton	132
	Rockbridge	C011	Lexington	117
	Rockingham	C033	Elkton	216
	Rockingham	C042	Dayton	206
	Page	C211	Luray	159

Speed (columns 35-37)

The test speed is automatically entered in columns 35-37 for each skid test run.

Milepoint (columns 38-41)

The milepoint location of each skid test is automatically recorded in columns 38-41.

End of Word Code (column 42)

An end of word code is automatically entered in column 42 for each skid test.

Left Wheel Skid Force (columns 43-46)

When testing with the left wheel the left wheel skid force is automatically entered in columns 43-46.

Right Wheel Skid Force (columns 47-50)

When testing with the right wheel the right wheel skid force is automatically entered in columns 47-50.

Pavement Condition (column 51)

When testing the control loop code the pavement condition as shown below.

Condition	Code
Dry	1
Damp	2
Wet (water flowing on surface)	3

Leave column 51 blank for normal survey testing.

Time Since Last Rain (columns 52-53)

When testing the control loop code the time since the last rain (since last wet surface condition) at the site being tested correct to the nearest day. Leave columns 52-53 blank for normal survey testing.

If the pavement condition is coded as 3 the time since the last rain should be coded as 000.

Open (columns 54-55)

Columns 54 and 55 are left open for future use. Do not code columns 54 and 55.

Data Type (column 56)

The type of highway feature tested should be coded as shown below.

Data Type	Code
Main line of highway	0
Bridge	2
Daily Control Sites (1st Tests)	7
Daily Control Sites (2nd Tests)	8
Test Loop Data	9

District (column 57)

Code the appropriate district as shown below.

District	Code
Bristol	1
Salem	2
Lynchburg	3
Richmond	4
Suffolk	5
Fredericksburg	6
Culpeper	7
Staunton	8

Residency (columns 58-59)

Code the appropriate residency in columns 58 and 59 as shown below.

District	Residency	Code
Bristol	Wise	01
	Abingdon	03
	Lebanon	04
	Tazewell	06
	Wytheville	08
	Jonesville	58
Salem	Hillsville	09
	Christiansburg	11
	Martinsville	12
	Rocky Mount	13
	Salem	14
	Bedford	16
Lynchburg	Chatham	17
	Halifax	18
	Dillwyn	19
	Appomattox	20
	Amherst	22

District	Residency	Code
Richmond	South Hill	23
	Amelia	24
	Petersburg	25
	Chesterfield	26
	Sandston	27
	Ashland	28
Suffolk	Franklin	31
	Waverly	32
	Suffolk	33
	Norfolk	34
	Williamsburg	35
	Accomac	36
Fredericksburg	Saluda	37
	Warsaw	39
	Fredericksburg	40
	Bowling Green	41
Culpeper	Louisa	42
	Charlottesville	43
	Culpeper	45
	Warrenton	46
	Fairfax	47
	Manassas	48
	Leesburg	49
Staunton	Lexington	50
	Staunton-Verona	53
	Harrisonburg	54
	Edinburg	55
	Luray	56

Calibration (columns 60-62)

Column 60 should contain the last digit of the year in which the calibration was performed. Columns 61 and 62 should contain the calibration number, assigned when the calibration was performed. For example, the tenth calibration performed in 1973, should be coded 310.

End of Word Code (column 63)

An end of word code is automatically entered in column 63 for each skid test.

End of Record Code (column 64)

An end of record code is automatically entered in column 64 for each skid test.

APPENDIX B

READ PAPER TAPE
(Repaper)

September 1973

Repaper is the property of and was developed for the Virginia Department of Highways by

Sarah A. Kelly
computer programmer

of the Data Systems and Analysis Section of the Virginia Highway Research Council.

The purpose of this program is to read and evaluate the paper tape output of the skid trailer digital data system.

The program reduces the skid force to a skid number by using a linear equation, of which the slope and intercept are input variables. Consecutive test records are compared and any change in the information given in the heading of the printout will result in a new page and heading containing the revised data.

DECK SET-UP

1. Operator Request Card
2. Red Header Card
3. Request (Paper, TR)
4. Compass (L = 0)
5. Load (LGO)
6. Load (Input)
7. Execute (rdpaper, p1 p2, p3 P6)
8. Rewind (Tape 30)
9. Copysbf (Tape 30, output)
10. Rewind (Tape 30)
11. Run (G)
12. LGO
13. CR data card
14. Flex 1 conversion deck

15. CR data card
16. Binary CO14/Rdpaper conversion deck
17. CR data card
18. Program deck
19. Blue end card

The paper tape and the slope and intercept variables are the only input to the program.

APPENDIX C

SKID DATA USED IN STUDY

Series Number	Air * Temperature °F	Number of Tests	Average D	Average A	Standard Deviation D	Standard Deviation A	Average Difference	Mean Square D	Mean Square A
1	52	10	60.3	56.5	2.31	1.58	3.8	48.02	22.47
2	52	10	49.9	47.4	3.18	2.63	2.5	91.01	62.25
3	52	10	57.1	49.7	2.51	3.06	7.4	56.70	84.27
4	52	10	50.2	40.5	3.55	3.54	9.7	113.42	112.78
5	52	10	58.9	47.0	4.82	2.11	11.9	162.63	40.07
6	52	10	48.3	39.5	2.25	2.42	8.8	35.44	52.71
7	52	10	55.9	45.5	4.57	3.54	10.4	167.08	112.78
8	52	10	43.5	34.0	2.73	3.16	9.5	67.08	89.87
9	52	10	52.1	42.0	2.77	3.94	10.1	69.06	139.71
10	52	10	39.2	30.0	4.26	4.22	9.2	163.33	160.28
11	76	10	65.9	53.6	2.22	1.33	12.3	44.36	15.92
12	76	10	54.6	43.2	2.59	2.35	11.4	60.37	49.70
13	76	10	62.1	49.8	3.93	2.86	12.3	139.00	73.62
14	76	10	49.0	38.2	4.92	3.79	10.8	217.86	217.86
15	76	10	61.7	49.6	3.84	4.09	12.1	117.96	150.55
16	76	10	47.9	35.4	4.61	4.09	12.5	191.27	150.55
17	76	10	61.1	50.1	2.51	3.00	11.0	56.70	81.00
18	76	10	43.1	35.1	5.24	4.20	8.0	47.12	158.76
19	76	10	58.3	48.1	3.74	3.00	10.2	111.90	81.00

Series Number	Air * Temperature °F	Number of Tests	Average		Standard Deviation		Average Difference	Mean Square	
			D	A	D	A		D	A
20	76	10	41.1	33.2	4.68	3.73	7.5	111.56	139.71
21	76	10	54.4	46.2	1.78	2.74	8.2	28.52	67.57
22	76	10	45.1	36.3	4.53	4.00	8.8	184.69	144.00
23	76	10	53.2	42.5	3.39	3.31	10.7	103.43	98.60
24	76	10	41.8	32.5	4.37	2.99	9.3	171.87	80.46
25	76	10	52.7	42.2	3.20	2.44	10.5	92.16	53.58
26	76	10	42.5	32.0	3.69	3.84	10.5	122.54	117.96
27	76	10	50.6	41.4	1.35	.97	9.2	16.40	8.47
28	76	10	36.2	30.3	5.41	4.92	5.9	263.41	217.86
29	76	10	48.9	41.2	3.28	3.33	7.7	96.83	99.80
30	76	10	34.8	28.4	1.81	2.50	6.4	29.48	56.25
31	88	5	57.6	45.4	.89	.89	12.2	3.96	3.96
32	88	10	52.1	40.8	1.05	2.15	11.3	8.82	41.60
33	88	10	56.1	44.4	2.60	1.71	11.7	60.84	26.32
34	88	10	47.6	37.4	3.89	3.31	10.2	136.19	98.60
35	88	10	55.1	44.2	2.42	2.10	10.9	52.71	39.69
36	88	10	44.0	34.0	2.40	1.63	10.0	51.84	23.91
37	88	10	54.0	42.6	4.11	3.71	11.4	152.03	110.22
38	88	10	43.2	32.8	3.36	3.05	10.4	101.61	83.72

Series Number	Air * Temperature °F	Number of Tests	Average		Standard Deviation		Average Difference	Mean Square	
			D	A	D	A		D	A
39	88	10	53.3	42.3	2.63	2.95	11.0	62.25	78.32
40	88	10	40.9	31.6	2.18	1.65	9.3	42.77	24.50
41	88	10	54.4	44.4	1.78	.97	10.0	28.52	8.47
42	88	10	45.1	37.0	4.53	4.97	8.1	184.69	222.31
43	76	10	50.8	41.0	1.99	1.94	9.8	35.64	33.87
44	76	10	40.5	32.3	1.90	2.58	8.2	32.50	59.91
45	76	10	50.0	40.6	3.33	2.67	9.4	99.80	64.16
46	76	10	42.2	32.7	6.44	6.70	9.5	373.26	404.01
47	76	10	49.1	39.4	2.92	3.27	9.7	76.74	96.24
48	76	10	36.8	28.9	3.74	2.69	7.9	125.89	65.12
49	76	10	48.2	39.3	4.78	4.14	8.9	205.64	154.26
50	76	10	36.6	28.0	5.40	3.40	8.6	262.44	104.04
51	68	9	63.4	59.8	1.92	3.63	3.6	92.24	105.42
52	68	10	51.6	47.9	3.27	3.35	3.7	96.24	101.00
53	68	10	61.9	56.7	2.28	2.11	5.2	46.79	40.07
54	68	10	47.2	43.4	2.66	2.80	3.8	63.68	70.56
55	68	10	60.7	55.1	3.56	4.84	5.6	114.06	210.83
56	68	10	45.6	42.4	3.54	2.67	3.2	100.25	64.16
57	68	10	63.0	57.3	4.23	4.30	5.7	136.89	166.41

Series Number	Air * Temperature °F	Number of Tests	Average D	Average A	Standard Deviation D	Standard Deviation A	Average Difference	Mean Square D	Mean Square A
58	68	10	44.0	40.1	4.78	3.21	3.9	205.64	92.74
59	72	10	63.9	56.3	4.23	4.24	7.6	143.14	161.80
60	72	10	43.2	38.7	3.65	3.47	4.5	119.90	108.37
61	72	10	61.5	56.9	2.80	3.28	4.6	70.56	96.83
62	72	10	49.0	47.6	8.69	4.72	6.4	679.64	200.51
63	72	10	56.1	50.9	3.96	2.81	5.2	141.13	71.06
64	72	10	48.6	42.2	4.01	2.28	6.4	144.72	20.79
65	82	10	58.2	47.3	3.99	3.23	10.9	143.28	93.90
66	82	10	45.1	40.2	3.51	7.18	4.9	110.88	463.97
67	82	10	56.2	45.2	4.29	4.52	11.0	165.64	183.87
68	82	10	44.3	35.4	2.87	2.76	8.9	74.13	68.56
69	82	10	56.9	46.4	4.31	4.06	10.5	167.18	148.35
70	82	10	41.3	30.9	5.01	4.79	10.4	225.90	206.50

* $^{o}C = (^{o}F - 32) \times \frac{5}{9}$

APPENDIX D

OPERATING PROCEDURE FOR VIRGINIA SKID VEHICLE

(Essentially a modification of the procedure given in reference 3.)

The recommended method of operation for the skid resistance measurement vehicle using the digital data recording system follows essentially the same steps as those used for operation without it. Automatic control has been applied to all parts of the test cycle where it was feasible to do so. An outline of the recommended instrumentation operating method is as follows:

1. Position the control transfer switch so that control is in the instrument operator's compartment.

2. Turn the DC master switch on.

3. Start the engine driven generator and allow it to operate for five minutes. The generator output voltage should be between 110 and 125 volts, and the frequency should be between 58 and 62 Hz.

4. Turn the following instruments on and allow them to warm up for 30 minutes:

   a. Strip chart recorder;
   b. Digital data coupler;
   c. Digital recorder control panel;
   d. Skid force counters;
   e. Milepost counter;
   f. Vacuum pump.

5. Set the digital clock to the correct time.

6. After 30 minutes, select a low paper speed for the strip chart recorder and place the recorder switch in the continuous position. Balance the strain gage preamplifiers following the instructions furnished by the instrument manufacturer.

7. Select the strain gage preamplifier attenuation that will give the desired measurement sensitivity.

8. Adjust the strain-gage preamplifier pen position controls to give the base line pen deflection, on the strip chart, that was used on the last valid calibration. (For simplicity, this will usually be five lines.)

9. Place the recorder switch in the record position. If a strip chart record is desired, select the desired chart speed for the strip chart recorder, if not, the recorder should be turned off.

10. Set the milepost counter to the present location of the measurement vehicle.

11. Enter all manually collected data by manipulating the digital selector switches.

12. Select the test wheel that is to be used and place the brake and water switches for that wheel in the on position. Place the nozzle switch for the test wheel in the down position.

13. Turn the paper tape punch on and transfer the control position to the towing vehicle cab if this is desirable.

14. Engage the power take-off unit.

15. Drive the measurement vehicle to the pavement area that is to be investigated, maintain the desired measurement speed, and depress the test-start button every time a measurement is desired. The test-start button should not be depressed more often than once each six seconds unless an extended measurement is required.

The data collection system is shut doen by turning off the power switches on all of the instruments in the reverse of the instrument start up order.