

MICHIGAN DEPARTMENT OF STATE HIGHWAYS
EQUIPMENT FOR MEASURING
PAVEMENT SKID RESISTANCE

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PAVEMENT SKID RESISTANCE

Research Laboratory Section
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Michigan State Highway Commission
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Lansing, February 1971

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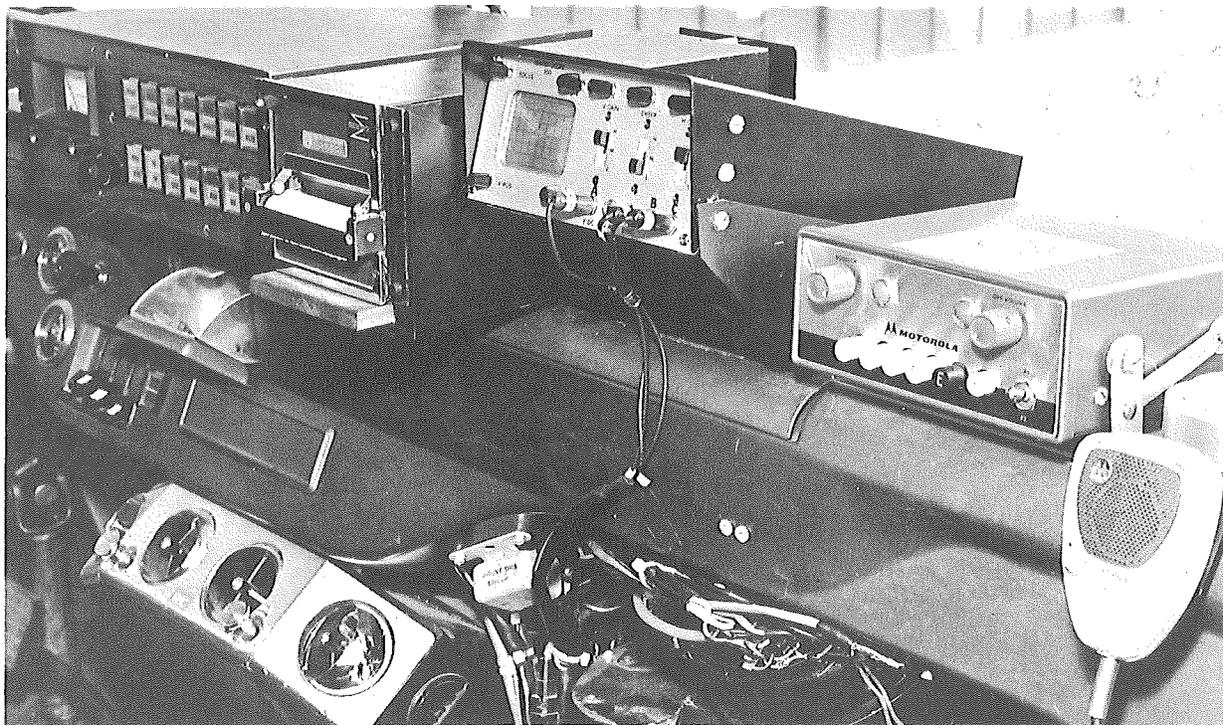
This report describes the equipment and procedures used by the Michigan Department of State Highways for determining the coefficient of wet sliding friction of pavement and bridge surfaces. The measuring system is of the self-contained, towed two-wheel trailer type (Fig. 1).



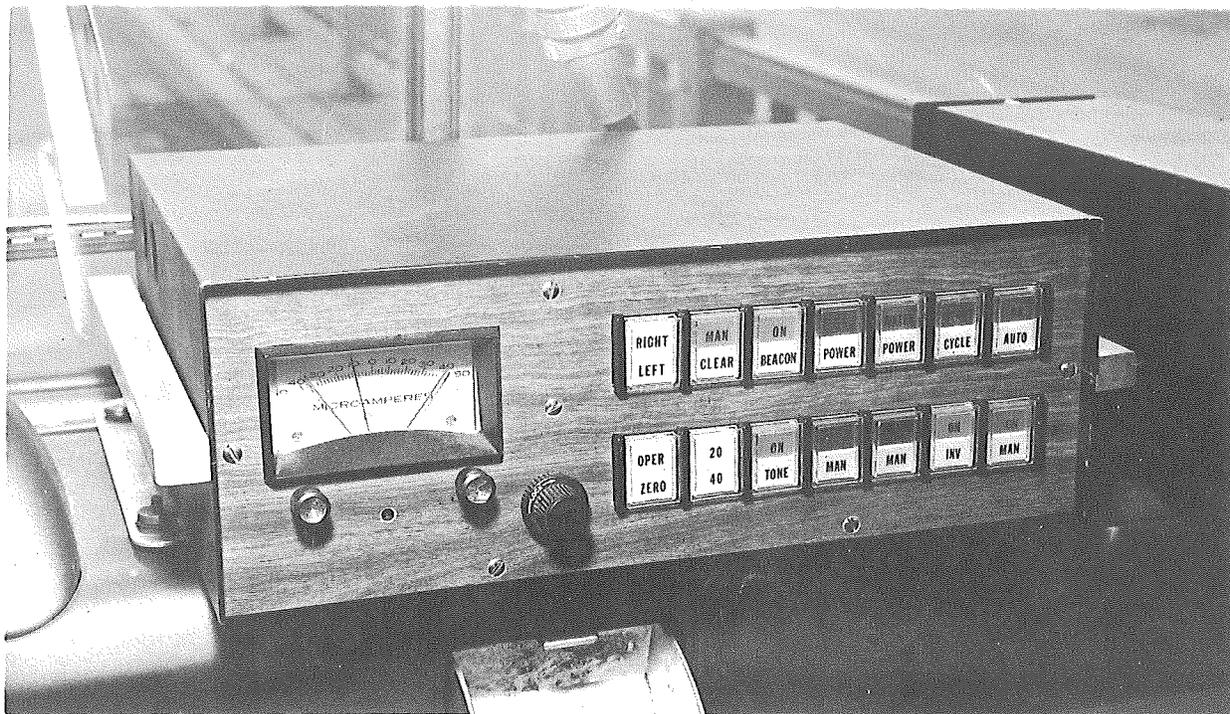
Figure 1. Tow vehicle and skid trailer.

Tow Vehicle

The tow vehicle currently in use (our fifth replacement) is a 1970 Chevrolet Tilt-Cab Model TE 51803 with a 97-in. wheelbase and a 366 cu in. V-8 engine. It is equipped with vacuum-assisted hydraulic brakes, hydraulic power steering, and Allison automatic transmission. Advantages of this vehicle include excellent sight distance from a relatively high cab, 360-degree visibility, short turning radius, and sufficient power to pull the trailer at a constant speed during tests.



Overall view showing (left to right) system controller, digital printer, monitor scope, and two-way radio.



System controller with tone-generating speed controller (20 or 40 mph set-point speed meter at left).

Figure 2. Dash-mounted control units.

A. Tow Vehicle Accessories

1. Body: special pickup type, 9 ft 6 in. by 7 ft 6 in. by 1 ft 6 in.
2. Water System: two tanks with combined capacity of 450 gal, jointed by a 2-in. equalization pipe and pressurized to a regulated 35 psi. Water is spilled from two 1-in. pipes, at a rate of 3.5 gal per test, in such a manner that it strikes the pavement surface at a 45-degree angle in the trailer wheel paths. Water release is controlled by normally closed, 12 vdc solenoid valves.
3. Power Supply - Compressor Unit: Externally mounted package powered by a 4 cycle, 12 hp engine (Kohler model K3015) driving a 12 cu ft air compressor (Quincy model 216) with 1690 cu in. air tank and a 60 amp Delco alternator with full transistor regulator and 12 vdc storage battery.

B. Instrumentation

1. System and Cycle Controller:

This shock-mounted unit in the center of the vehicle dashboard provides complete system control by either operator or driver. The controls (illuminated push button type) indicate modes and sequences of operation and provide system alarms. Figure 2 shows the layout of the units and a close-up view of the controller.

The following is a description of the switch and indicator functions.

(a) Right - Left wheel movement detector.

Two solid-state proximity switch amplifiers (Micro-Switch No. 20 FLI) mounted under the truck dash are connected to proximity switch sensors (Micro-Switch No. 204 FSI) mounted on each of the skid trailer wheel backing plates. A steel, ten-fingered disc connected to the moving wheel and positioned in close proximity to the sensors provides detection of any wheel movement greater than 36 degrees (Fig. 3). Activation occurs only when skid tests are being performed, at which time the sensor detection signal is presented to wheel movement logic circuitry in the controller. If movement is detected during the skid an alarm light will be actuated which identifies the slipping wheel.

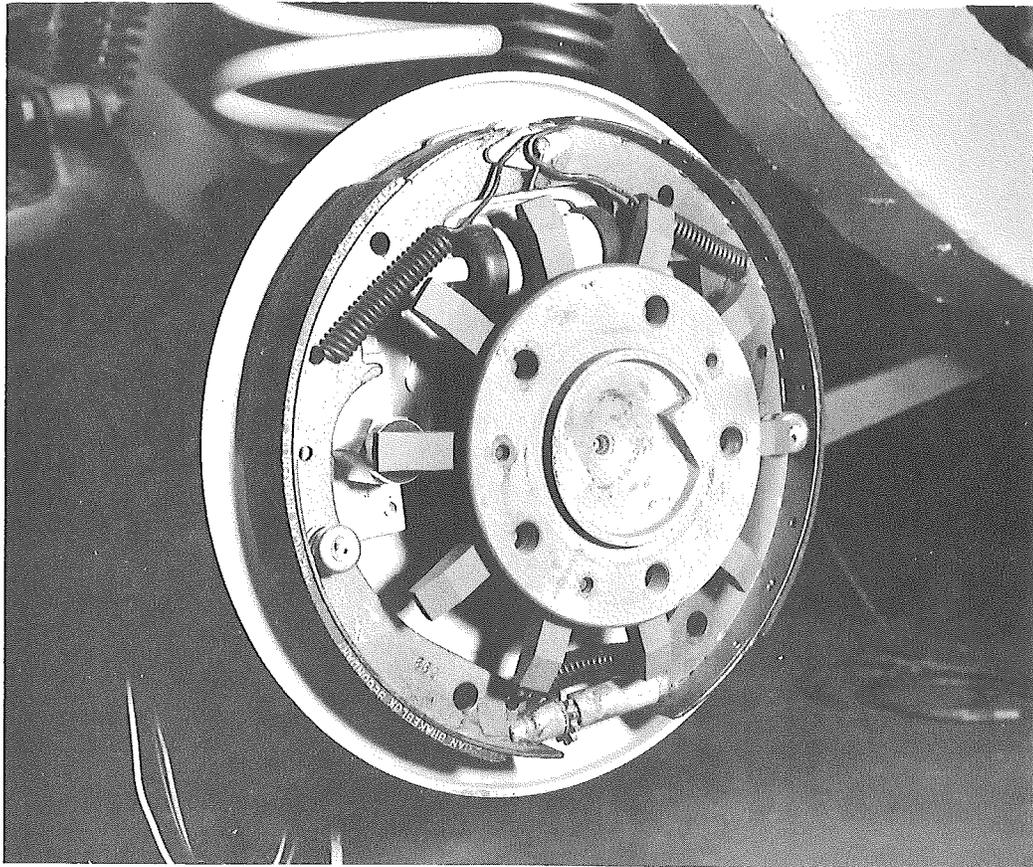


Figure 3. Skid trailer wheel showing proximity switch sensor.

Alarm indication will be held until such time as the Man Clear button is actuated or until the start of next skid cycle, at which time the alarm is automatically cleared.

(b) Beacon, Brake, and Water Power Controls

These push buttons control and confirm power application to the vehicle warning light and to the trailer brake and water solenoids. Also Man Brake and Man Water push button indicators are provided for system check out.

(c) Man On and Auto On Controls

The system operator may select either Man On or Auto On mode of operation by push button. In the Man On Mode all operations must be initiated by push button. In the Auto On mode a Cycle Start push button initiates an automatic cycle

of operations--the water solenoids are activated, 0.7 seconds later brake solenoids are energized and power is held to both for an additional 1.9 seconds to complete the skid test cycle.

(d) Other Controls

The controller also includes switch indicators for 115 vac inverter and speed indicator operation. Speed is determined by a d-c tachometer generator attached to the truck drive train. Its output is compared to a stable push-button selected reference for speeds of 20 or 40 miles per hour. A visual null meter is also provided with the high and low set points to provide high and low speed audible alarms. The normal operation range of these set points is approximately ± 0.5 mph.

2. Digital Skid Coefficient Recording System:

This conditioning and recording system was designed to produce a digital printout, in engineering units, of pavement skid coefficients 0.2 seconds after a test completion. To retain the malfunction detection properties of analog format, a long-persistence monitor oscilloscope is included in the system. This enables the operator to view the complete analog signal which is being converted to a digital coefficient.

A typical 40 mph Michigan analog skid test record and timing cycle is shown in Figure 4.

A 20 mph record would be similar except that the breakaway amplitude would be less and the "start uniform sliding" point would fall to the left, or earlier in the cycle.

The function of the digital system is to sense the start of the skid cycle, then delay until the signal reaches the uniform sliding area. Then at that point (t_1) begin integrating the area under the curve and continue integration until point t_2 is reached. At that time the integrated mean voltage is converted to a digital signal and fed to the digital printer.

During the test period, the entire analog signal, including the t_1 and t_2 timing pulses, is displayed on the monitor screen.

Specifications for the system are attached.

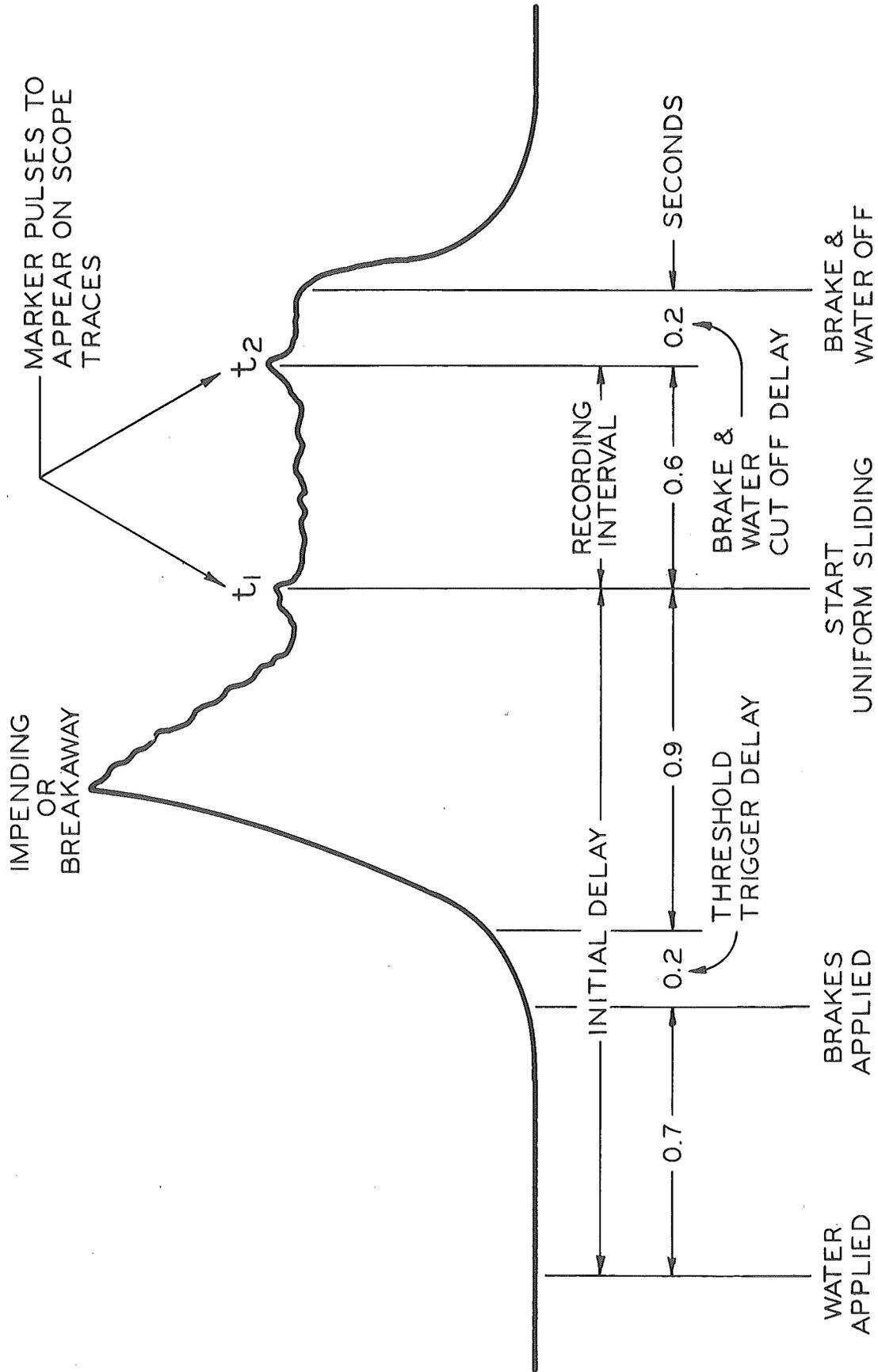


Figure 4. Typical 40 mph analog skid record and timing cycle.

Trailer

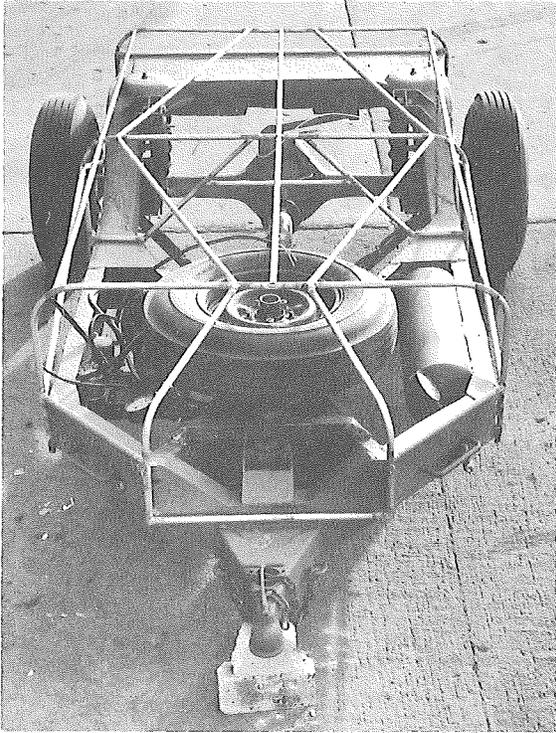
The trailer was originally constructed from a salvaged 1949 Buick frame, rear axle, and torque tube, with standard Buick braking system but has since been almost totally modified. Figure 5 shows the trailer without its sheet aluminum cover.

A. Trailer Specifications

1. Brake actuation system: 45-psi air pressure over hydraulic (1,500 psi) pressure, activated by 12 vdc solenoids (Fig. 6).
2. Wheel suspension: coil springs and spring/oil shock-strut damping (Fig. 7).
3. Tow hitch: oversized (house trailer type) ball-and-socket hitch located 10-3/4 inches above pavement and transversely midway between the wheels, 93.9-in. longitudinally forward of the trailer axle centerline.
4. Cover: aluminum sheet, riveted together in sections and removable in one piece.
5. Weight: 1,750-lb axle and 146-lb hitch. Weight is controlled and distributed by lead cast over the axle.
6. Tires: standard 7:50-14 tire as specified in ASTM Designation E 249-64 T. Tires are used only for testing. For en-route traveling, regular automotive tires are used to avoid excessive wear on the test tires.

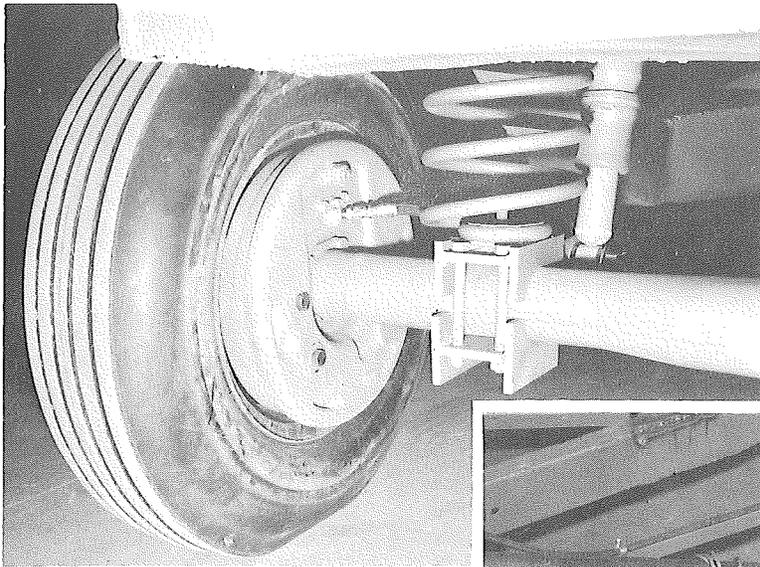
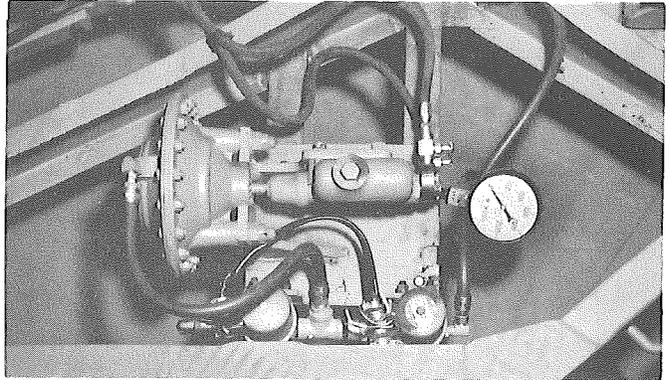
B. Instrumentation

1. Torque tube. Two Micro Measurement 350-ohm No. Ed-DY-250BG-350 strain gages are mounted on top and bottom of the vertical axis of the torque tube, 4-1/2 in. forward of the rear torque tube shoulder (Fig. 8).
2. All cabling is selected to maintain high electrical insulation properties under conditions of dampness and water spray, particularly at strain gage connection points. Vibration and shock are controlled by use of clamps or shock mounts.



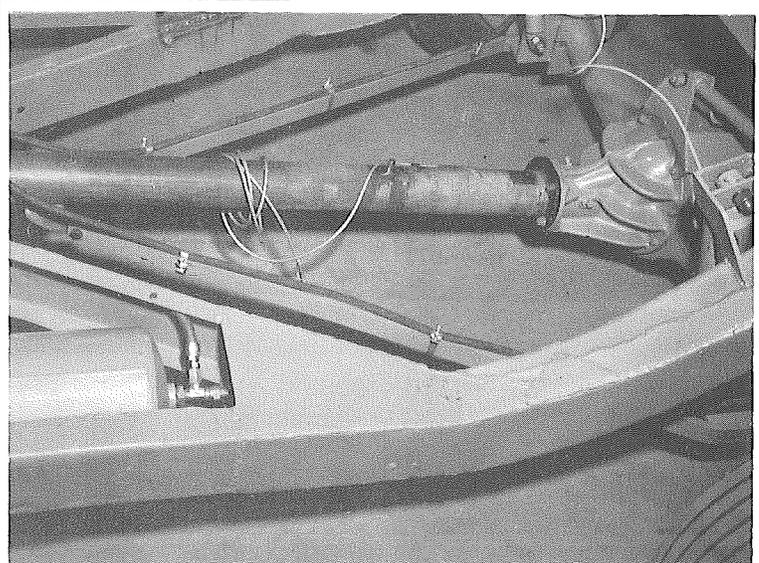
◀ Figure 5. Skid trailer, shown during refurbishing with cover frame in place prior to mounting aluminum sheet cover.

Figure 6. Top view of brake actuation system, showing master cylinder, pressure diaphragm, control solenoids and pressure gage.



◀ Figure 7. Test tire and trailer wheel suspension system.

Figure 8. Torque tube, showing strain gage mounting area. ▶



Calibration

A. Equipment

1. Laboratory strain sensing and recording equipment
2. Calibrating platform with skid-resistant pads
3. Two (series-wired) load cells with connecting rods
4. Loading bar and supports
5. Loading chains and equalizing bar
6. Loading cylinder and mount
7. Electrically controlled hydraulic pump

B. Procedure

1. Anchor loading cylinder securely to floor
2. Position loading platform appropriate distance (gaged by length of loading chains) from, and centered upon, loading cylinder.
3. Place load cells with connecting rods between loading bar and skid-resistant pads of calibrating platform.
4. Secure loading chains to loading bar in such a manner that loading cylinder throw is sufficient to allow adequate movement of skid-resistant pads. Adjustment can be made by shortening or lengthening chain links.
5. Connect hydraulic pump to loading cylinder.
6. Place trailer in position on skid-resistant pads of loading platform making certain trailer is properly aligned (tires parallel to direction of applied load) and level.
7. Connect torque tube strain gage lead and calibration load cell leads to recording equipment.

8. Proceed with desired calibrating measurements by locking truck and trailer brakes and applying a uniform rate of loading with hydraulic pump until trailer tires slide on skid-resistant pads. Repeat loading procedure until at least three successive similar traces are recorded.
9. Following loading procedure, a calibration load equivalent must be recorded for the balance resistor (560 K) to determine an equivalent coefficient of friction for "black box" balance gain adjustment and printout.
10. Determine the relationship between load cell output (lbs) and torque tube output by taking a reasonable number of simultaneous points from each recorded trace. Use this relationship to establish the drag force in pounds represented by each increment of torque tube output.
11. Complete calibration by determining torque tube output (drag force) representing various values of μ in the following equation:

$$\mu = \frac{F_d}{F_n - F_d} \frac{h}{L_w}$$

where:

μ = Coefficient of sliding friction

F_d = drag force

F_n = normal force

h = height of center of hitch ball above ground level in inches.

L_w = horizontal distance from hitch ball centerline to trailer axle centerline in inches.

12. Using the same equation, compute equivalent μ value for the balance resistor and adjust "black box" gain to produce required digital print out. Figure 9 shows the system calibration set-up.

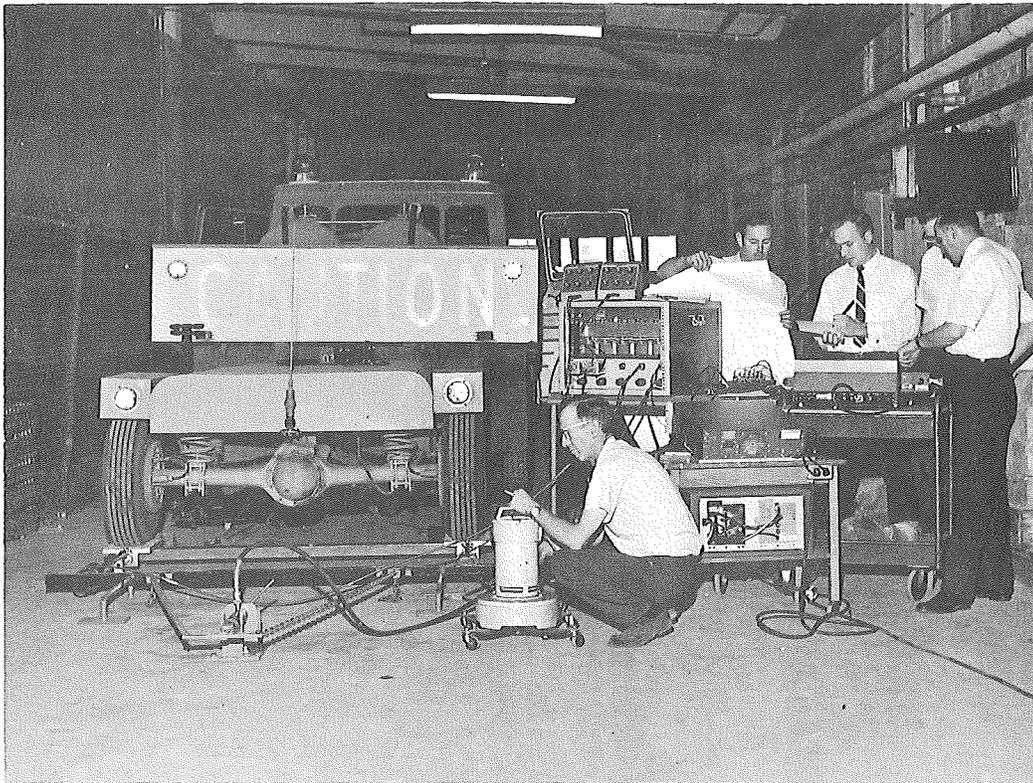


Figure 9. Calibration of skid system.

Determination of Valid Skid Coefficients

A. Field Testing Procedure

1. Speed is determined by the testing situation. For intersections and short test runs, a 20 mph speed is used; for open areas, 40 mph. Speed measurement control is calibrated at 20 and 40 mph. At other speeds it is necessary to use the backup speed-indicating instrumentation. All data are reported as 40 mph wet sliding friction values. Conversions from 20 mph are based on conversion factors determined experimentally from 10, 20, 30, and 40 mph skid tests on both concrete and bituminous pavements.
2. At intersections, conduct at least three tests in the last 200 ft of each lane (the "stopping area") in such a manner that the same pavement is not included in more than one test. (For example, divide the last 200 ft into thirds and conduct one test in each third.)

3. At other locations, determine the minimum number of randomly selected tests from the following table:

Usable Length (miles)	Minimum Tests per lane
0-3	3
3-4	4
4-5	5
5-6	6
6-7	7
7-8	8
8-9	9
9-10	10

Drive over each project prior to testing in order to determine the amount of usable mileage available.

B. Verification of Test Results

The following table established the degree of variation with a given test series that is acceptable without the necessity of additional tests:

UPPER CONTROL LIMITS FOR SKID COEFFICIENT RANGES

Probability of Exceeding Range	Average Skid Coefficient	Number of Samples*									
		3	4	5	6	7	8	9	10	11	12
0.050	0.0 - 0.19	.048	.051	.053	.055	.059	.062	.064	.064	.066	.068
0.025	0.20 - 0.33	.058	.062	.064	.067	.067	.069	.071	.074	.074	.076
0.010	0.34 - 0.46	.065	.067	.072	.074	.077	.077	.079	.081	.081	.084
0.005	0.47 - 0.52	.072	.074	.077	.077	.079	.081	.081	.084	.084	.086
	0.53 - 0.65	.083	.085	.087	.089	.091	.091	.093	.095	.095	.097

* Values in the "Number of Samples" columns are expressed in coefficients of friction (μ) and indicate the maximum allowable differences between highest and lowest readings--in other words, the ranges.

1. If a series of tests ($S_{\bar{x}}$) exceeds the maximum acceptable degree of variation, or upper control limit, run the following checks:
 - a. Check for a physical explanation in the surface tested. If an area of surface difference can be established, it should be tested separately.

- b. Check for malfunction of equipment. If found, note and correct, and re-run all tests affected.
- c. If neither a surface difference nor equipment malfunction is indicated, repeat the test that produced the "out-of-control" range (this will usually be one of the three tests run and will be obvious in that its value will be significantly different from the other two). If the significantly different value is verified as correct, run a complete second test series (S_2), using particular care to test different areas from those tested in S_1 . If the significantly different value is not verified as correct, conduct at least two more tests in the same location and use the average of the second test plus these two to replace the aberrant S_1 point.

NOTE: The above sampling and verification plan is designed such that greater precision is required in the lower, more critical, coefficient range.

Field Test Records

The following items of project information are to be recorded in the field for each project tested.

- A. Date
- B. Temperatures (pavement and air)
- C. Location and project number
- D. Test number with digital skid coefficient
- E. Tire pressure and tread depth
- F. Intersection diagram (to be attached to field test record form)
- G. Test speed and surface type
- H. The following factors are known to effect skid resistance measurements and therefore should be controlled if possible. If they are not amenable to control their existence in a test project should be recorded:
 1. Test speed
 - a. magnitude
 - b. variation during test

2. Test tires
 - a. wear
 - b. pressure
 - c. temperature
3. Pavement surface wetting
4. Brakes: ability to keep wheels locked when braking
5. Geometric factors
 - a. grade
 - b. traffic or passing lane
 - c. lateral placement in lane
 - d. crown
6. Surface factors
 - a. oil drippings
 - b. soil, sand, or silt
 - c. painted traffic stripes
 - d. roughness
 - e. bleeding
 - f. faulted joints
 - g. joint seal extruded or recessed
 - h. temperature

SPECIFICATIONS FOR
AUTOMATIC, TRANSISTORIZED DIGITAL OUTPUT SYSTEM
FOR PAVEMENT SKID MEASURING EQUIPMENT

Input:	Half bridge, 350-ohm gage (customer supplied).
Bridge Completion Resistors:	Built in.
Balance Control:	Front panel, screwdriver adjust (coarse) and locking knob (fine).
Calibration:	Built in, front panel switchable resistor.
Bridge Excitation:	10 volt dc.
Gain Control:	Front panel, screwdriver adjust.
Test Control:	A test push button provided which simulates a trigger point to be utilized during calibration.
Outputs:	<p>(a) A 3-in. monitor oscilloscope with P-7 long persistence CRT, triggered by the start of strain gage bridge output and giving a single sweep for each test. Sweep speed 0.5 to 2.5 sec (3.0 to 15 cm/sec) and vert, amp, as required.</p> <p>(b) Marker pulses to be added to the bridge output at the beginning and end of recording interval for display on monitor CRT only.</p> <p>(c) A three digit printout, in skid coefficient units accurate to 1 percent. This printout is the result of digitizing the integrated value of the bridge output during the indicated recording interval. Filtering to remove the effects of superimposed ripple and noise is used only at the CRT monitor.</p>

Initial Delay and Recording Interval: System provides for two operating positions, each having independent initial delay, integrating time and gain control. Internal screwdriver controls to permit the adjustment of both the initial delay and recording interval over the range of 0.1 to 1 second.

System Trigger: Internal screwdriver threshold adjustment which automatically initiates the test cycle by sensing bridge output signal.

Power All power to be provided by a 12-vdc to 115-vac, 60 cps inverter or as required. Source current from battery not to exceed 18 amps.

Mounting:

- (a) Monitor oscilloscope and printer mounted as a single remote unit with shock mounts and provided with inter-connecting cable, 8 ft long.
- (b) The system electronics package should not exceed 19 in. wide by 10 in. x 12 in. deep, also being shock-mounted.
- (c) Inverter shock-mounted with connecting cables for remote mounting up to 10 ft from electronics package.

Temperature: All silicone semi-conductors are to be used in system electronics including scope, printer, and inverter to permit storage up to at least 75 C and operation up to 60 C.

Accuracy: System accuracy of 2 percent over a temperature range of 0 C to 60 C and with line voltage changes of ± 10 percent.

Miscellaneous:

Interconnection Wiring:

All interconnecting cable between system packages is to be provided including mating connectors. The shielded wiring between the strain gage bridge and electronics package will be supplied by customer.

Manuals:

Two instruction and service manuals are to be included. These manuals are to include system block design, schematics, trouble-shooting voltage and signal test point information, description of the system operation, and the location of component parts and circuit cards. Also, replacement parts list.

Extender Cords:

An extender cord is to be supplied to facilitate maintenance on circuit boards.

Warranty:

This system will be guaranteed for all failures and out of specification performance, except abuse, for a period of one year. Any faulty items will be returned to supplier for repair or replacement at no cost to customer.

Source:

Michigan's Digital Output System

Information Instruments, Inc.
62 Enterprise Drive
Ann Arbor, Michigan 48106

(Approximate cost - \$5,800.00)

