FAA National Runway Friction Measurement Program

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Measurements of runway friction, pavement surface conditions and engineering data for 491 runways at 268 U.S. airports are used for statistical analysis to develop guidance materials to ensure the design and maintenance of nonslippery surfaces at United States airports. Friction values are analyzed as they relate to pavement type, texture depth, grooving, and rubber accumulation. The basic concepts of Advisory Circular 150/5320-12 are supported by the data. Corrective maintenance action is recommended for friction values. The results of the contractors findings will be considered in the revision of Advisory Circular (AC) 150/5320-12, Methods for the Design, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces.

FAA National Runway Friction Program

Objectives

On September 29, 1978, the Federal Aviation Administration (FAA) embarked on a two-year study with its contractor, E.A. Hickok and Associates, to obtain friction and pavement condition data on 491 runways at 268 airports in the contiguous United States.

The purpose of the program was to provide a large data base on which statistical analyses could be performed and from these analyses develop further guidance on matters of design and maintenance of nonslippery, wet pavement surfaces. The specific objectives of the program as set forth in the contract were to:

1. Update, expand and disseminate improved guidance material contained in AC 150/5320-12 on runway friction and related airport safety items.
2. Provide airport managers with timely input for fiscal programs.
3. Increase effectiveness of the Airport Development Aid Program (ADAP) by identifying the airport pavement construction methods most effective in providing good friction characteristics.
4. Enhance safety by reducing hydroplaning and improving runway friction characteristics by development of recommendations for improved maintenance and maintenance monitoring practices.

The program was conducted in two phases, the first phase was localized in the Southern Region where 28 airports and 52 runways were surveyed. This phase was a shake-down on the procedures and performance of personnel and equipment before undertaking the next phase, which encompassed the entire contiguous United States.

Scope of Work

The airports were asked to voluntarily participate in the program by each FAA regional office and all responded favorably.

The qualifications for an airport to participate in the study were that they had to have at least one ILS (Instrument Landing System) runway serving scheduled turbojet operations within the contiguous United States.

Schedule and Training

Testing was scheduled to assure a minimum of three surveys at least 60 days apart at each airport participating in the program.

At the beginning of each phase, an extensive classroom and field training course was conducted at Dulles International Airport in Washington, D.C. The contractors senior staff personnel provided training to the field crews on the procedures to be used in conducting friction and pavement condition surveys.

Figure 1 shows a group of trainees receiving field training on conducting friction and pavement condition surveys.

Friction Survey Equipment

Tow vehicles

Supercab pickup trucks were used to tow the friction trailer, the Mu-Meter. The vehicles were equipped to conduct surveys at day or night. Specifically, they were provided with exterior flood light and speakers, rotating beacon, a 340-gallon water tank and automatic speed control. Figure 2 shows a tow vehicle conducting a friction survey.

TABLE 1. SCOPE OF WORK

Region	Airports	Runways	Surveys
Central	19	39	118
Eastern	32	62	180
Great Lakes	49	104	298
New England	10	18	48
Northwestern	15	22	61
Rocky Mountain	28	45	118
Southern	56	95	297
Southwestern	33	65	185
Western	26	41	113
Total	268	491	1,418

Figure 3 shows the interior equipment in the tow vehicle, the automatic printout recorder and distance computer.

Friction trailer

The friction equipment used was manufactured in the United Kingdom. The device, called a Mu-Meter, measures the pavement side-force friction. The Mu-Meter is a three-wheeled trailer. The side wheels measure pavement friction as the rear wheel drives the recorder when proceeding down the runway. The strip chart located inside the recorder, records continuous friction values. Figure 4 gives a closeup of the Mu-Meter and figure 5 shows the interior of the recorder.

Figure 6 shows a closeup of the self-water system used by the Mu-Meter. The system provides a specified depth of water in front of the friction measuring wheels.

Pavement Condition Survey Equipment

Distance Computer

To measure the distance down the runway, a distance measuring computer was used. The location of rubber deposits or other pavement features such as ruts, cracks, spalling etc., required an accurate device to determine location of specific events. Figure 3 shows the device located on top of the automatic printout recorder. The device was equipped with a 30-register memory which allowed rubber accumulation values at different locations along the runway to be stored for later recall. A dictaphone was also used to record pavement surface conditions.

Fawley Slope Bar

Spot tests were conducted at four different locations along the runway. Usually they were taken at the touchdown areas, center and one off to the side of the runway. To determine the transverse slope of the runway, a Fawley slope bar was used. The slope bar was a four foot level with a cam mounted on one end to vary the vertical distance from that end of the level to the runway. Figure 7 shows the cam at one end of the level.

Radiant Temperature Thermometer

The pavement surface temperature was determined by using a radiant temperature thermometer at the beginning of each friction survey. Figure 8 shows the instrument measuring the pavement temperature.

Texture Depth Measurement

Texture depth was determined by performing the NASA grease smear test, along with stereo photographs taken at each site. Figures 9 and 10 depict the grease smear test and photographic equipment. The personnel when conducting the grease smear test applied a known volume of grease to a four inch wide test area. The grease was smeared with a squeegee over the test area until expended. The length of the area was measured. The average texture depth was calculated by dividing the known volume of grease by the area covered.

Stereo photographs of the pavements surface were taken with two 35-mm cameras, the cameras were mounted on a metal frame at a precise angle to assure the overlap needed to produce stereoscopic pairs. The height was set at 24 inches to assure the same scale for each photograph.

Storage of equipment and office space was provided by a travel trailer as shown in figure 11.

Data Entry Equipment

Figure 12 shows a portable terminal which connects the user to the computer through any common telephone. The survey team used the terminal to transmit and receive messages, and transmit data from the friction and pavement condition surveys.

Field Procedures

To assure that the data gathering process was complete and without extraneous information, a list of data parameters was developed and followed throughout the entire program. The data was divided into two categories, friction measurements and airport inventory. Table 2 lists the friction measurement data parameters and Table 3 lists the airport inventory data parameters.

TABLE 2. FRICTION MEASUREMENT DATA PARAMETERS

Dry Mu values - 500-foot averages
Wet Mu values - 500-foot averages
Pavement, Air, and Water temperature
Date, Time
Rating and Location For:
- Asphalt or Concrete
- Type of finish
- Grooving type, Grooving condition
- Rubber accumulation
- Structural distress
- Joint or crack condition
- Paint type
- Paint condition
- Contaminant type
- Contaminant coverage
- Depressions, ruts

Spot Tests:
- Location and offset from centerline
- Transverse slope
- Texture measurements
- Groove dimensions (spacing, width, depth)
- Rubber accumulation
- Mu-Values - dry and wet
- Stereo photographs

TABLE 3. AIRPORT INVENTORY DATA PARAMETERS

Airport name
Runway identification
Airport designator
Key personnel - names, titles, phone numbers
Airport mailing address
Master plan date
Airport layout plan date
Aerial photograph date
Frost depth typical for area
Runway utilization
Landings by aircraft type
For Each Runway:
- Length, Width, Elevation, Effective gradient

Design transverse slope
Date of most recent painting
Marking type
Paint type and condition along centerline
Grooving date
Original construction - date, material, finish, length and location
Subsequent additions and overlays - date, material, finish, length and location
Seal coating date
Design aircraft, weight and landing gear
Soil classification
Drainage condition
Rubber removal - date, method
Blast pads or displaced thresholds location and length
Previous friction measurements - date, results, source
Pavement tests, soil tests, dates
Know pavement deficiencies:
- Rutting
- Shoving due to traffic
- Faulting of slabs
- Excessive cracking
- Frost bumps during winter
- Longitudinal grade change
- Transverse grade change
- Poor drainage
- Loss of crown
- Groove closing
- Surface wear
- Rubber accumulation
- Other

Accident History:
- Date, Runway, Equipment involved

Friction Survey

Prior to measurements at each airport, survey teams performed a functional check on the Mu-Meter in accordance with the manufacturer's instructions. Figure 13 shows the survey team performing a functional check on the Mu-Meter. At the starting end of the runway, the Mu-Meter measuring wheels were put in test position and the tow vehicle was aligned ten feet to the right of the runway centerline. The dry friction survey was started after obtaining clearance from ground control. The tow vehicle was brought up to 40 mph within the first 500 feet and maintained at this speed by the automatic speed control until the final 200 feet. The survey team observed runway surface changes and monitored the APO digital display to make certain that the Mu-Meter was functioning properly. A dry survey was also performed on the opposite side of the runway.

In the same manner, wet friction runs were conducted on the runway. After the tow vehicle was positioned at the end of the runway, the survey team lowered the water distributing brushes and recorded the amount of water in the tank. The length of time the pump was activated and the amount of water used were determined to compute the flow rate.

Pavement Condition Survey

The Pavement Condition Survey was the assessment of pavement surface conditions throughout the runway based on visual observations, and measurement of surface conditions at four spot test locations. The main area of concern on the runway was in the Mu-Meter testing tracks, from 8-12 feet on either side of the centerline.

During the first test run of the pavement condition survey, a record was made of the following surface conditions for the entire runway length: pavement type, grooving type and condition, contaminant type and coverage, paint type and coverage, cracks, joints, and rut or depression depth. Additional pavement data were collected at four spot test locations. The spot tests included photographs, transverse slope measurements, groove spacing measurements, and the NASA grease smear test.

The final test run of the pavement condition survey was to measure rubber accumulation. Rubber accumulation was rated based on the percent of the texture that was obliterated by the rubber. The entire testing time for Mu-Meter runs and two pavement condition survey runs was approximately 1-1/2 hours per runway.

Data Evaluation

The survey team evaluated and coded the data for computer input. All the Mu-Meter strip charts were evaluated: The continuous trace was divided into 500-foot segments of runway surface and an average Mu-Meter surface friction value (Mu value) was determined for each segment. The Mu values were also read for each spot test location on the runway.

Limits of acceptability were established to provide guidance to the survey teams. Reasonable agreement between the average surface friction for an entire runway for two passes, separated by at least 60 days, was considered to be $\pm$ 3 Mu values. When comparing three passes, the Mu value tolerance between the highest and lowest runway Mu averages was $\pm$ 4, and for four passes, $\pm$ 4.5. In addition, each individual 500-foot segment Mu value was to be within the tolerance of $\pm$ 6, $\pm$ 8 and $\pm$ 9 for two, three and four passes respectively. Survey team members also checked that the strip chart profile was similar for all passes. If a runway fell outside these guidelines, it was further investigated, and if necessary retested.

The chief goal of the study was to obtain data of pavement surface friction characteristics at all the airports selected to participate in the program. All other data were utilized to provide for correlation with the friction measurements.

Generally, the field procedures fell into five major categories: Airport contact meeting, Airport Inventory, Mu-Meter Friction tests, pavement condition surveys, and data evaluation.

Quality Control

In any large data-gathering process, it is important that the data is accurate and reliable. To assure that this was accomplished, quality control procedures were developed. Quality control was divided into two major tasks. The first was to insure consistency in survey team procedures and quantitative judgments. The second was to insure accuracy in transferring raw data to computer files, forms, and reports.

The contractor prepared a manual on quality control procedures and senior staff members of the contracting firm periodically checked the survey teams to evaluate their performance.

Computer Operations

To handle the large mass of data accrued in the study, a computer capable of accepting 650,000 individual data items was selected. The Direct Access Computing time-sharing network services of McDonnell Douglas Company (McAUTO) was used for data access and communications. This system has nationwide access and is based on a CDC Cyber 175 Computer.

Communications are vital in a nationwide study such as this. Immediate communications between survey teams, contractors office and FAA office personnel was available throughout the study. Each day the survey teams reported their locations, status of surveys, and any comments pertaining thereto.

At the completion of each airport survey, the survey teams coded and entered the data using the portable computer terminal. The results of all airport surveys were immediately available for examination and processing by the contractor and FAA personnel.

The data generated at each airport site was assembled in a standard format and presented to the airport operator, according to the guidance given on FAA AC 150/5320-12.

The statistical analyses of the data obtained in the study were performed using the Statistical Program for Social Sciences (SPSS). The SPSS is a nationally vended computerized statistical package selected for its capability for analzing extensive data with large number of variables. To organize the data, a data base was developed using System 2000 on a CDC Cyber computer.

Engineering Evaluation

This program produced an enormous amount of data, including replicate friction measurements of the entire length of every scheduled turbojet runway in the contiguous United States. From a statistical standpoint, the data does not represent just a sampling, but en masse measurement of the whole runway population of interest.

The major portion of the data consists of Mu values averaged over 500-foot long runway segments. The data base contains some 42,000 of these segments. In addition to surface friction values, each segment is characterized by pavement material and finish, presence or absence of grooving, groove condition, rubber accumulation or removal, texture, and other pertinent pavement characteristics such a paint markings, ruts, depressions and drainage (slope).

The data analysis was guided by continual inspection of the data to identify unique situations that could be verified prior to drawing any conclusions.

Evaluation of Pavement Types

The data obtained in the study showed that seventeen distinctive pavement surfaces, based on material and finish were identified. A total of 28 pavement types had sufficient data for analysis and Table 4 shows the wet mu values for each pavement type. It is apparent from the data in Table 4 that grooving and rubber accumulation have significant effects on pavement surface friction. The 28 pavement types are ranked by mean surface friction value, see figure 14.

Table 5 shows the mean texture depth for various pavement types. Figure 15 ranks the pavement types by mean texture depth. From figure 16, the two curves for asphalt and concrete pavements reflect that surface friction is dependent on texture.

The data also indicates that texture depth increases with pavement age. This can be attributed to the increased exposure of aggregate in the pavement as the matrix materials weathers or is worn away.

To quantify the aging effect on texture, a linear regression analysis was performed for ungrooved asphalt pavement in traffic areas with no rubber accumulation. The results indicate that texture depth increases approximately 3.4 thousandths of an inch per decade, with a standard error of 1.1 thousandths of an inch per decade. Data on concrete pavements was insufficient for similar analysis.

Generally, for nontrafficked areas, weathering rather than wear is a chief factor for increase in texture depth for asphalt pavements. The above analysis excluded porous friction course and friction seal coats.

Evaluation of Pavement Grooving

It is not surprising that grooved pavements enhance surface friction and mitigates hydroplaning. In the study, it was found for various grooved pavement types that a one-inch difference in groove spacing corresponds typically to a five-wet mu value difference in friction, with a standard error of one wet mu value per inch. The analysis also indicates that surface friction increases as groove spacing decreases. Therefore, it is more desirable from standpoint of friction to use smaller groove spacings. The standard groove spacing of 1¼ inches center to center was the best performer in the study and also the smallest observed. As grooves deteriorate in condition, the enhancement of friction also decreases slightly.

Evaluation of Rubber Removal Effectiveness

Rubber deposits on wet runway pavement surfaces significantly reduce the effective friction for aircraft operations. Generally, it was found that the lowest wet friction values occur in areas of highest rubber accumulation. Likewise, where rubber has been removed, friction increases to the friction level of the clean pavement surface. Figure 17 shows a typical runway friction profile and the effects of rubber accumulation/removal.

The contractor has developed a family of curves (figure 18) showing the relationship between rubber removal frequency versus annual aircraft landings for several pavement types. The curves can be used as a guide for establishing a maintenance program for a particular runway at an airport. The figure indicates the required rubber removal frequency for the "average pavement" of each type. Maintenance of a particular runway should be based on direct observations of rubber accumulation and periodic friction measurements.

Table 6 lists a suggested schedule for conducting friction surveys at an airport, based on annual landing weight of the most heavily used runway. The annual landing weight can be determined by finding the total number of annual landings of each type of aircraft landing at an airport. The annual landings of each type of aircraft should then be multiplied by the corresponding maximum landing weight. The sum of these values will produce the annual landing weight at the airport. The annual landing weight should then be multiplied by the percentage of landings on the most heavily used runway end. The resulting runway end annual landing weight should be used in Table 6.

TABLE 6 . SUGGESTED SCHEDULE FOR FRICTION SURVEYS

Runway End Annual Landing Weight (million pounds/year)	Frequency of Friction Surveys: Ungrooved Pavements	Frequency of Friction Surveys: Porous Friction Course Saw-Cut Grooved Wire Tined
Less than 1000	Annual	Annual
1000-2000	6 months	Annual
2000-4000	3 months	Annual
4000-8000	1 month	6 months
8000 and above	Monthly or more often as required	6 months

CONCLUSIONS

Rubber accumulation on runway pavements profoundly affects surface friction. These effects have been quantified for various pavement types and range from 1.6 to 6.9 wet Mu value decrease per unit increase in rubber accumulation rating.

Rubber removal improves runway surface friction characteristics.

Saw-cut grooving improves runway surface friction. The friction enhancement due to grooving is greater in areas of rubber accumulation than in uncontaminated areas for most pavement types.

For low-use runways, a reasonable basis for comparing and ranking the surface friction characteristics of various pavement types is provided by mean wet Mu values for uncontaminated areas. (See Table 4 and Figure 14.)

TABLE 4 MEAN WET MU VALUES FOR PAVEMENT TYPES

ASPHALT PAVEMENTS

Type	Wet Mu Value: Mean With No Rubber	Wet Mu Value: Mean With Rubber*
New	61.9	46.8
Microtexture	65.8	54.5
Mixed Texture	68.4	50.9
Macrotexture	74.1	55.7
Worn	74.6	55.1
Porous Friction Course	77.4	67.4
Chip Seal	75.1	--
Rubberized Chip Seal	73.0	--
Slurry Seal	70.2	--

ASPHALT WITH SAW-CUT GROOVES

Type	Wet Mu Value: Mean With No Rubber	Wet Mu Value: Mean With Rubber*
New	73.2	63.7
Microtexture	75.0	66.5
Mixed Texture	73.7	64.8
Macrotexture	73.5	67.4
Worn	71.6	--

CONCRETE PAVEMENTS

Type	Wet Mu Value: Mean With No Rubber	Wet Mu Value: Mean With Rubber*
Microtexture	57.9	47.6
Macrotexture	66.2	--
Worn	64.2	--
Burlap Dragged	57.9	49.1
Broomed or Brushed	63.3	54.7
Wire Combed	68.6	58.3
Wire Tined	69.1	63.0
Float Grooved	65.6	54.7

CONCRETE WITH SAW-CUT GROOVES

Type	Wet Mu Value: Mean With No Rubber	Wet Mu Value: Mean With Rubber*
Microtexture	71.1	60.0
Macrotexture	69.7	--
Worn	72.0	--
Burlap Dragged	73.7	65.0
Broomed or Brushed	69.2	62.8
Wire Tined	73.8	--

*Mean Mu value adjusted for 30 percent filling of texture by accumulated rubber, for pavement types with sufficient data for regression analysis. (See Section 2.6.4.1).

NOTE: Data include all uniform segments.

TABLE 5. MEAN TEXTURE DEPTH FOR VARIOUS PAVEMENT TYPES

Pavement Type	Mean Texture Depth inches x .001: Ungrooved	Mean Texture Depth inches x .001: Saw-Cut Grooved
Asphalt, Porous Friction Course	48.5	
Asphalt, Rubberized Chip Seal	39.9	
Asphalt, Worn	35.0	24.7
Asphalt, Macrotexture	27.7	23.3
Asphalt, Chip Seal	24.7	
Concrete, Wire Tined	22.2	20.9
Asphalt, Mixed Texture	19.3	15.9
Asphalt, Slurry Seal	19.0	
Concrete, Wire Combed	18.0	
Concrete, Macrotexture	16.5	12.0
Concrete, Broomed or Brushed	14.5	10.5
Asphalt, Microtexture	14.2	12.7
Concrete, Burlap Dragged	13.9	11.9
Concrete, Worn	12.8	12.8
Asphalt, New	12.5	15.3
Concrete, Float Grooved	12.5	
Concrete, Microtexture	12.4	11.0

NOTE: Data include all center spots (traffic area) with no rubber accumulation.

For high-use runways, guidelines have been developed for rubber removal frequency dependent on pavement type and annual landings. (See Figure 18.) These guidelines can be used in projecting and comparing annual costs of runway construction, resurfacing or pavement treatment alternatives, as well as in guiding maintenance of existing runways.

The Airport Survey Reports produced for each of the 268 airports after each testing provided timely input for airport maintenance purposes.

The purpose and objectives of the National Runway Friction Measurement Program were achieved. Mu-Meter measurements and Pavement Condition Survey data obtained in this program have yielded a rational and useful analysis of runway friction.

The Mu-Meter is a rapid and effective device for measuring surface friction when operated in accordance with the manufacturer's instructions.

The value of 50 has been in use for several years and this study did not disclose data to support another value. It must be understood that as friction decreases the relative safety decreases, but it is gradual and time-related, that is, when the Mu value decreases from 50 to 49 the pavement does not go from totally safe to totally unsafe.

The ranking of pavement types on the basis of mean texture depth closely follows the surface friction ranking. However, measurements of friction rather than texture are a preferable basis for planning routine runway maintenance.

Texture depth increases with pavement age, for typical pavements. The increase rate is approximately 3.4 thousandths of an inch per decade for asphalt pavements, and apparently somewhat lower for concrete.

The benefits of improved drainage and enhancement of friction due to grooving is greater for narrower groove spacing. A one-inch difference in spacing causes approximately a five Mu value difference in surface friction.

Groove deterioration produces a small effect on surface friction.

The rate of rubber accumulation on grooved runways is less than on ungrooved runways with the same level of usage.

Rubber removal reduces the maximum 500-foot runway segment rubber rating to approximately 2-2.5, corresponding to 20-25 percent texture obliteration or filling with rubber.

Rubber accumulation can be related to aircraft landings expressed as the summation of total landing weight on the runway end.

For low-use runways, rubber accumulation is dependent on annual aircraft landings (i.e., usage rate) and pavement type according to the scheme:

Annual Landings	Rubber Accumulation
Below 250 million lb/yr	Essentially zero for all pavement types
From 250 to 1,000 million lb/yr	Very low for all pavement types
From 1,000 to 5,000 million lb/yr	Linearly dependent on annual landings, with different slopes for different pavements

For high-use runways (having rubber removal), rubber accumulation is linearly dependent on cumulative aircraft landings since rubber removal (i.e., cumulative usage), with different slopes for different pavements.

Field observation indicates that it is difficult to remove rubber from the porous friction course pavements.

Wet Mu values can be corrected for calibration and adjusted to the reference temperature of 20°C.

Personnel can be adequately trained to operate and maintain the Mu-Meter to provide friction data for engineering and maintenance purposes provided they operate the equipment regularly.

The program has successfully demonstrated that personnel can be trained to observe rubber accumulation and other runway conditions on consistent and correlatable scales.

The large data base resulting from this program can, with relatively small additional data collection, be used to determine long-term maintenance and pavement requirements nationally, including such things as length and strength requirements.

Future analysis of the stereo photographs could provide significant findings on the characteristics of aggregate, microtexture and other factors which produce desirable friction.

Recommendations

The National Runway Friction Measurement Program has resulted in the following recommendations:

Pavement types having high surface friction, as identified in Figure 14, should be considered in the planning and design of new runway surfaces, particularly for low-use runways.

The guidelines for rubber removal frequency, as contained in Figure 18, should be used in planning and design of new runway surfaces and as a maintenance guideline, for high-use runways. Specific scheduling of rubber removal for an existing runway should ultimately be based on direct observation of rubber accumulation and measurement of surface friction.

The rating system used in this program for rubber accumulation should be formalized and promulgated for use by airport maintenance personnel.

Porous friction course, saw-cut grooving or other surface treatments should be considered for existing runway pavements with low surface friction.

The standard groove spacing (1-1/4 inches) should continue to be used.

The large data base from this program should be used to determine long-term runway maintenance and pavement requirements on a national basis.

Programs should be designed and implemented to define relationships of runway friction to ennvironmental factors (e.g., actual rainfall conditions) and aircraft performance.

Studies should be perfomed to evaluate rubber accumulation data and rubber removal effectiveness on porous friction course pavements.

Acknowledgments

The author wishes to acknowledge that the results reported in this paper were taken from the final report on the FAA sponsored contract: DOT-FA78WA-4242, National Runway Friction Measurement Program. The photographs, charts, and graphs in the paper were prepared by E.A. Hickok and Associates as well as the conclusions and recommendations.

References

1. American Society for Testing and Materials, "Standard Test Method For Side Force Friction on Paved Surfaces Using the Mu-Meter," ANSI/ASTM. E 670-79 (1979).

2. Federal Aviation Administration, "Methods for the Design, Construction and Maintenance of Skid Resistant Airport Pavement Surfaces," Advisory Circular 150/5320-12 (June 30, 1975).

3. M.L. Aviation Company, Ltd., Mu-Meter Instruction and Servicing Manual, White Waltham Aerodrome, Maindenhead, Berkshire, England (January 1975).

4. J.R. MacLenna, N.C. Wenck, P.D. Josephson, and J.B. Erdmann. National Runway Friction Measurement Program, Phase II Final Report. E.A. Hickok and Associates for Federal Aviation Administration (December 1980).

Figure 1. Personnel receiving instruction.

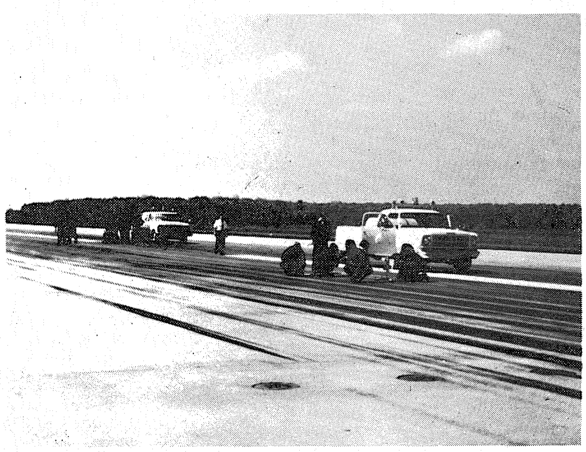


Figure 2. Tow vehicle and Mu-Meter.

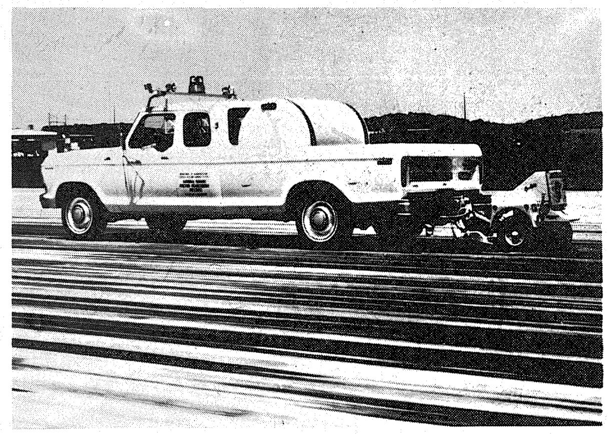


Figure 3. Automatic Printout-Recorder and Distance Computer in cab of tow vehicle.

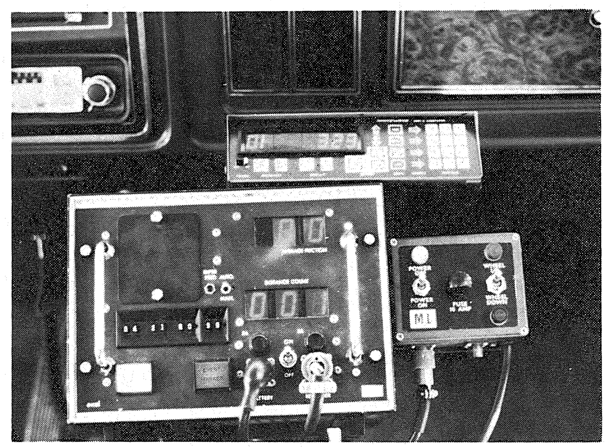


Figure 4. Mu-Meter friction tester.

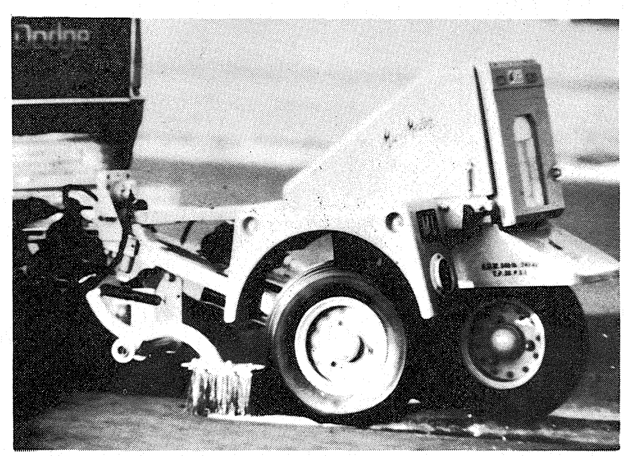


Figure 5. Closeup of Mu-Meter Recorder.

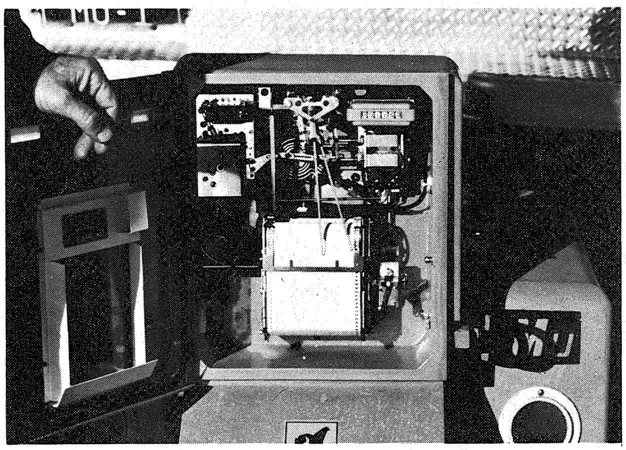


Figure 6. Self-watering system in operation.

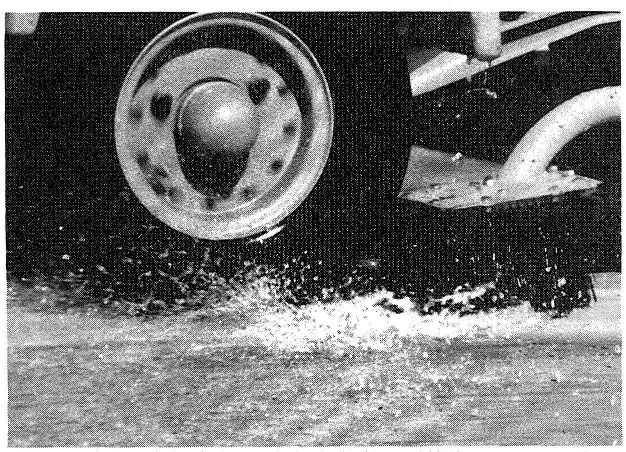


Figure 7. Closeup of the Fawley Slope Bar.

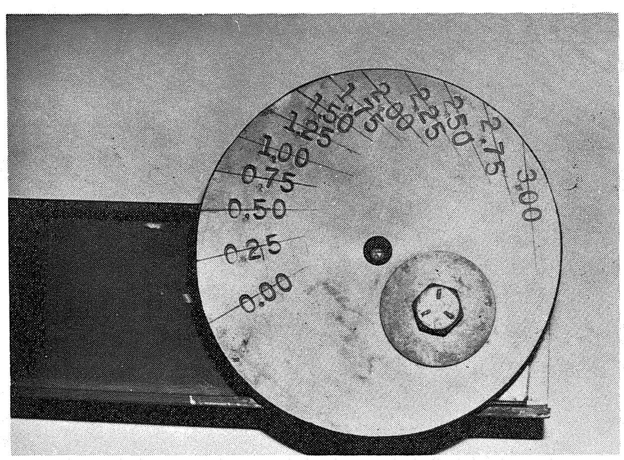


Figure 8. Radiant temperature thermometer.

Figure 9. NASA grease smear (right) and British Portable Tester (left).

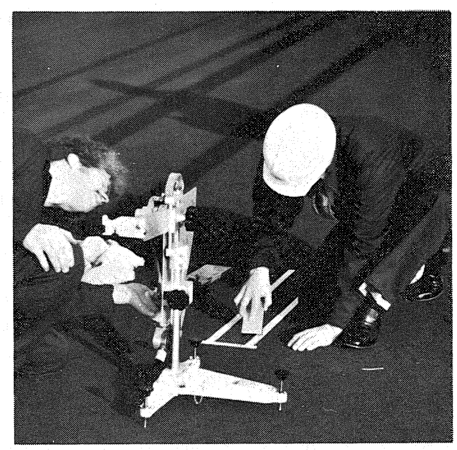


Figure 10. Color stereo photograph apparatus.

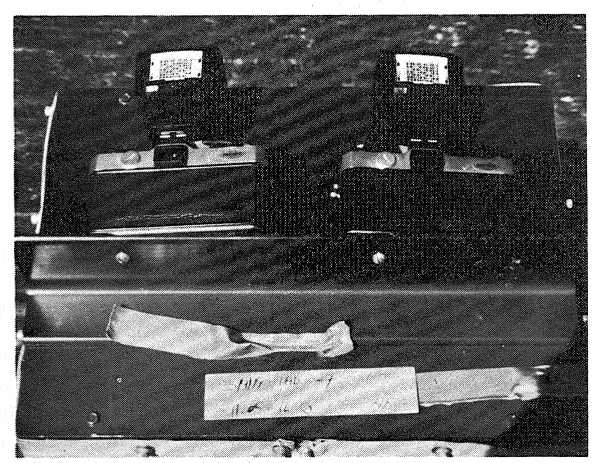


Figure 11. Travel trailer

Figure 12. Portable Computer terminal.

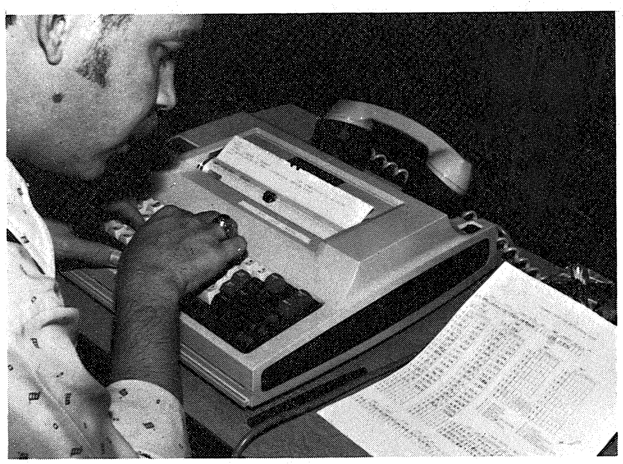


Figure 13. Functional check of the Mu-Meter.

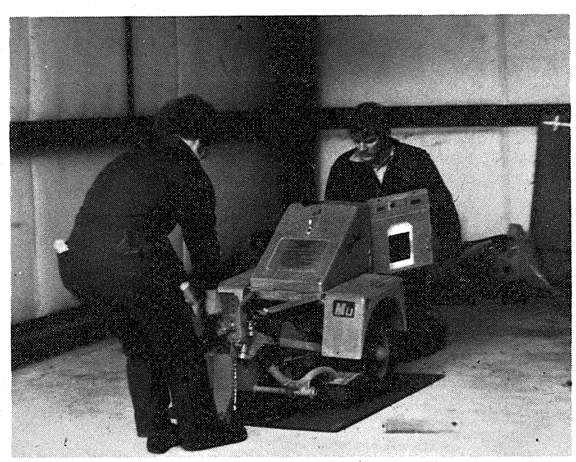
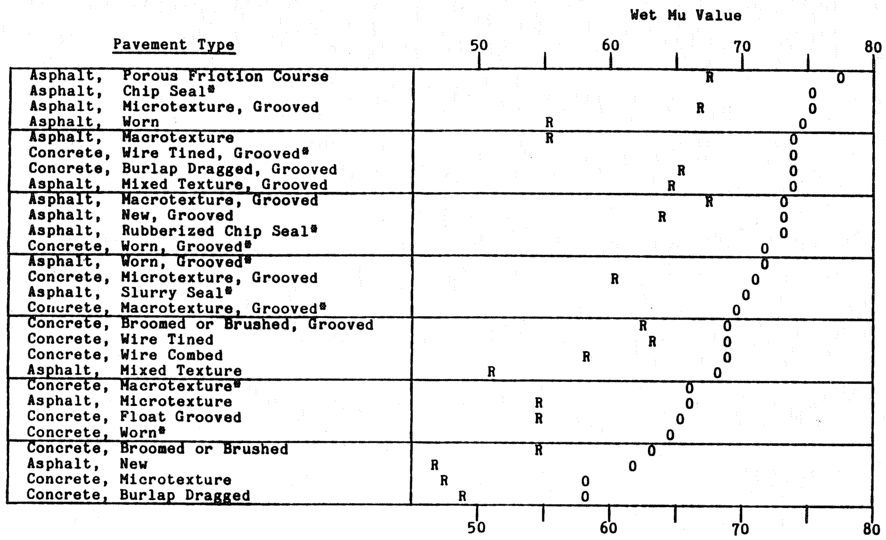


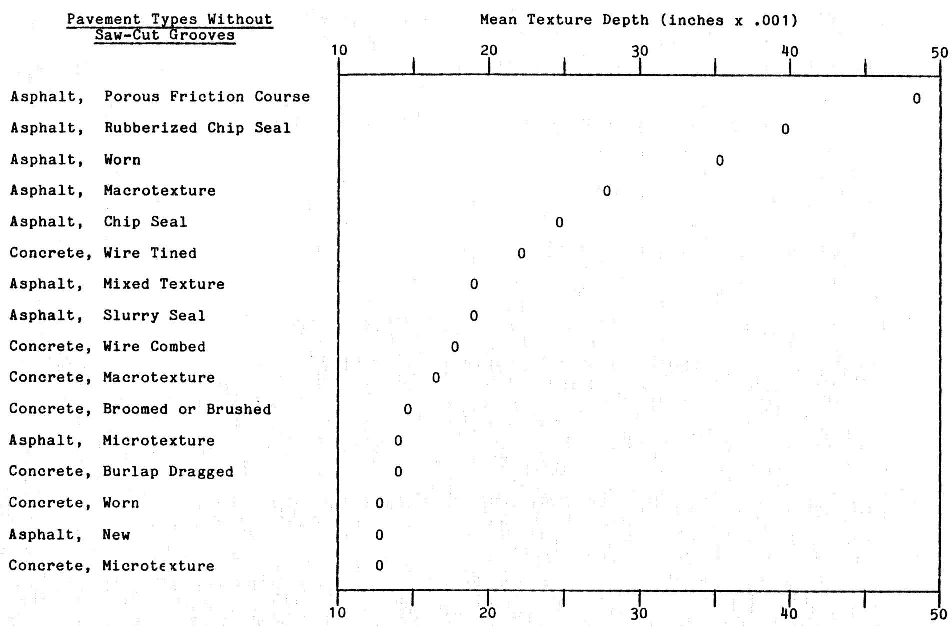
Figure 14. Ranking of Pavement Types by mean wet mu value.



0 - Mean Value with No Rubber
R - Mean Value in Rubber Areas (30% rubber accumulation)
* - Insufficient Data to Analyze in Rubber Area

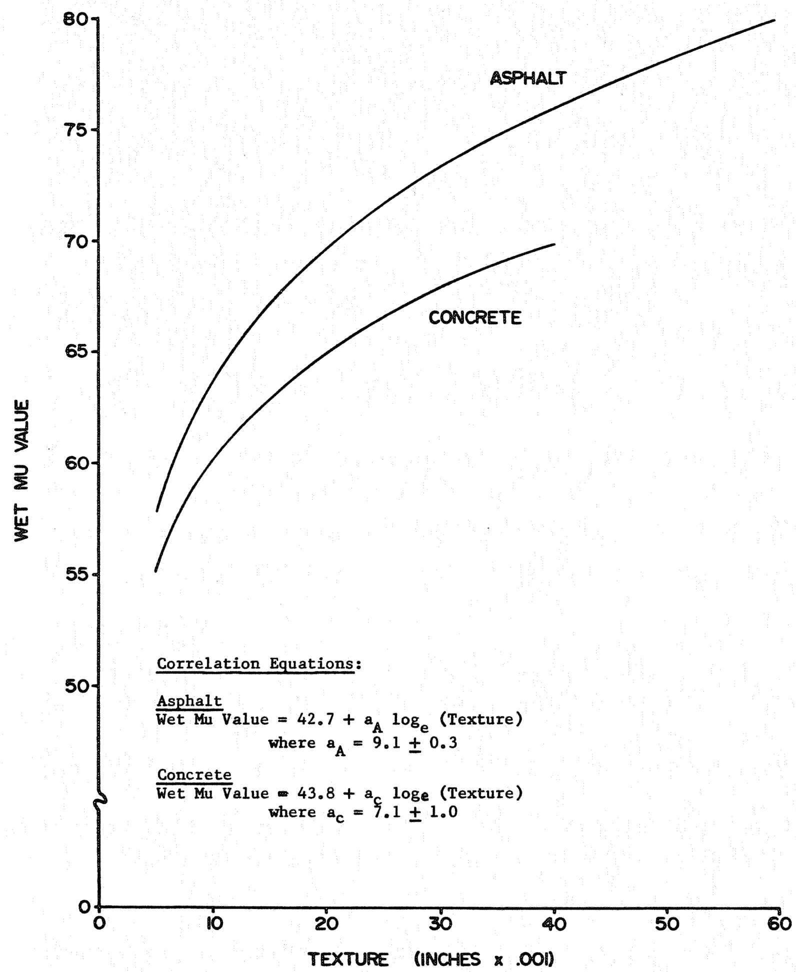
NOTE: Data include all uniform segments

Figure 15. Ranking of Pavement Types by mean texture depth.



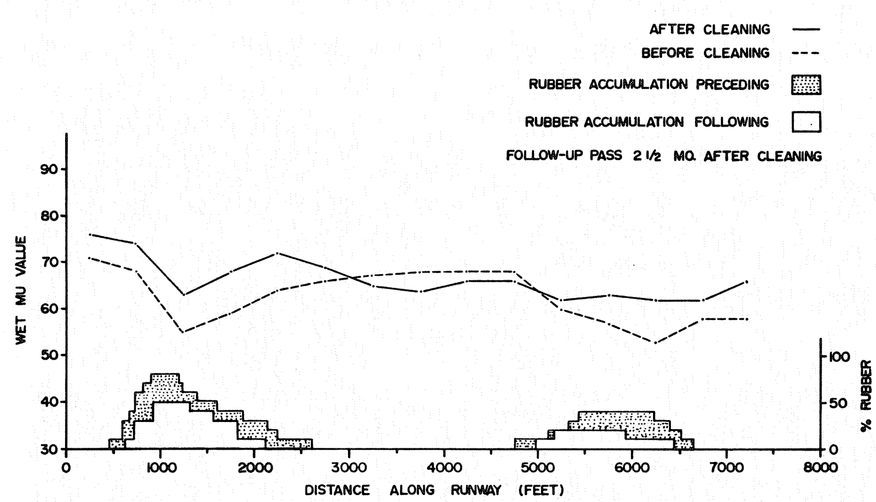
NOTE: Data include all center spots with no grooving and no rubber accumulation.

Figure 16. Relationship of wet mu value with texture depth for ungrooved pavements.



FRICTION RELATED TO TEXTURE

Figure 17. Example of effects of rubber accumulation and removal with respect to friction.



EFFECTS OF RUBBER ACCUMULATION AND REMOVAL

Figure 18. Rubber removal frequency for various pavement types.