NATIONAL BUREAU OF STANDARDS REPORT

7510

PROGRESS REPORT I

STANDARD MEASUREMENTS OF SLIPPERINESS ON WALKWAY AND ROADWAY SURFACES

by

Thomas H. Boone

and

Charles W. Auld

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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Organic Building Materials Section
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PROGRESS REPORT I

STANDARD MEASUREMENTS OF SLIPPERINESS ON WALKWAY AND ROADWAY SURFACES

1. INTRODUCTION

This report covers work done in FY1962 on the development of reference surfaces to serve as constant standards and for calibrating and comparing different types of friction-measurement equipment.

The report summarizes certain factors affecting friction, the study of a pendulum-type friction-measurement instrument, and the development and characteristics of some materials proposed as reference surfaces.

Values of slipperiness measurements on certain walkway and roadway materials are also given.

2. FACTORS AFFECTING FRICTION OF RUBBER

Friction is not a physical constant of any given material, but a function of both contacting surfaces, including the properties as well as the surface geometry of both materials.

The use of rubber in footwear and as tires for vehicles tends to govern its selection as one of the surfaces used in slipperiness studies.

Tabor [1] has shown that two main causes of rubber friction are shear, due to adhesion, and hysteresis. Under specific conditions, another term related to the cohesive properties of rubber may also be involved in resistance to sliding.

Generally speaking, a specimen of any material sliding on any clean or contaminated surface develops a resistance force in the plane of contact. Under specific conditions, this force may be purely viscous drag. In most practical cases, however, two or more terms are likely to contribute simultaneously.

The friction attributed to the adhesion, hysteresis, and cohesion terms are discussed in the descending order of their importance.

2.1 Friction Caused by Adhesion

A rubber block placed on a clean surface makes intimate contact with this surface in small zones, a_1, a_2, a_3,......a_n, distributed irregularly over the apparent block area, as shown in Figure 1. In these zones, the sum of which is defined as the actual contact area, molecular interaction forms minute adhesive bonds between rubber and surface. To move the block in the plane of contact or to slide it with constant velocity requires force enough to shear these bonds. The shear resistance, F, caused by adhesion is proportional to the actual contact area; the constant of proportionality being the shear strength, S.

2.2 Friction Caused by Hysteresis

When rubber slides on a sufficiently lubricated, wavy surface (see Figure 2), direct adhesional contact between rubber and surface cannot develop. As a consequence, the shear resistance due to adhesion must be zero. Any viscous drag is also negligible if the lubricating film remains thick enough and the sliding velocity is not excessive. However, a definite resistance, F, has to be overcome to maintain the sliding of the rubber block.

On a surface such as that shown in Figure 2, the rubber is subject to continuous deformation. The process of deformation is restricted to a relatively thin layer of the rubber block, and consists of a compression phase and an expansion phase. A certain amount of energy is required to compress the rubber element as it approaches an obstacle. When the block moves on, the element previously compressed can expand, but owing to hysteresis, it gives back only part of the stored energy. The difference between compression energy, Ec, and expansion energy, Ee, is lost to the rubber and converted into its heat equivalent, ΔE. To maintain energy equilibrium, the loss must be compensated by external work done on the rubber block. Hysteresis is therefore responsible for the resistance against sliding, F. This resistance, defined as friction caused by hysteresis is proportional to the hysteresis value of the rubber and the deformation it undergoes.

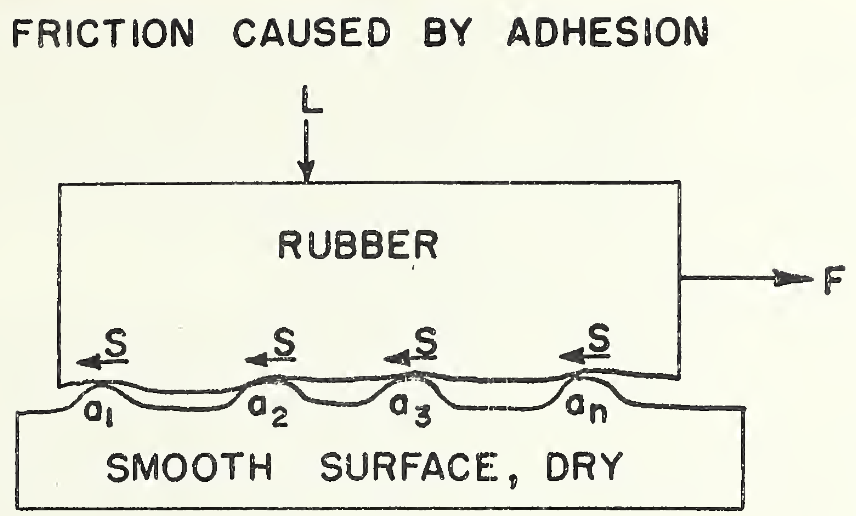

FIGURE 1. SCHEMATIC OF A MICROSCOPIC VIEW OF A SMOOTH, DRY SURFACE. L, NORMAL LOAD; F, PULL FORCE REQUIRED TO OVERCOME ADHESIVE SHEAR; S, SHEAR STRENGTH; AND a_1, a_2, a_3.....a_n LOCAL CONTACT AREAS.

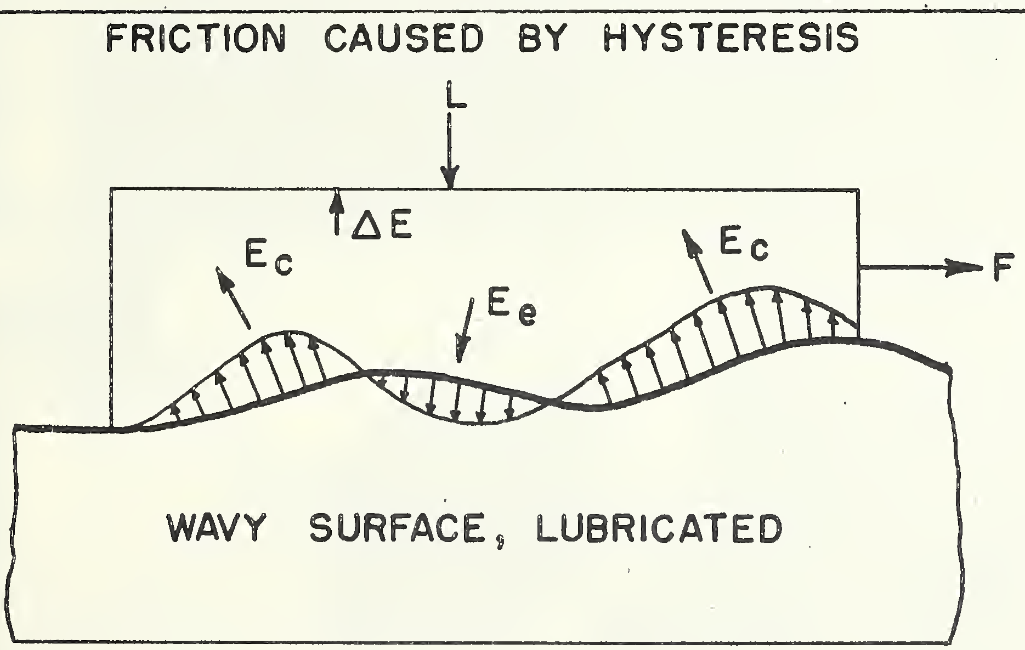

FIGURE 2. SCHEMATIC OF A WAVY, LUBRICATED SURFACE. L, NORMAL LOAD; F, PULL REQUIRED TO COMPENSATE FOR HYSTERESIS LOSSES; Ec, COMPRESSION ENERGY; Ee, EXPANSION ENERGY; AND ΔE, ENERGY LOSS (CONVERTED INTO HEAT).

2.3 Friction Caused by Cohesion

A knife-edge of finite length by negligible thickness and depth slicing through rubber has to overcome molecular cohesion. Because of the finite dimensions of the knife-edge or surface irregularities, this term is always accompanied by adhesion and hysteresis, and it seems impossible to separate the two latter terms from the first. It is likely that cohesion, as such, has very little effect on friction, but contributes indirectly by augmenting adhesion and hysteresis resistance.

In the general case, friction, F, of the rubber is the sum of the above three causes:

$$F = F(\text{adhesion}) + F(\text{hysteresis}) + F(\text{cohesion})$$

and the rubber properties influencing these three causes are: 1) composition, 2) physical properties, and 3) geometric properties.

3. PENDULUM METHOD OF MEASURING FRICTION

The pendulum method, based on conservation of energy, is a handy way to measure the relative slipperiness of surfaces, either in the laboratory or in the field. The principle was first reported by Sigler in 1943 on a large, table-mounted instrument [2], and again by Sigler, Geib, and Boone, in 1948 on a smaller, portable instrument [3]. The difference between the initial and final heights of the pendulum head is proportional to the average frictional force encountered by a rubber block (slider) when sliding over the surface. The value measured is relative, because the friction does not reach steady-state conditions. It is therefore referred to as "antislip coefficient" or "relative skid resistance".

This method approximates the conditions encountered by a tread element of a tire running under slip, or when the rear edge of a shoe heel contacts a surface, and in fact is believed to produce values more nearly representing the critical coefficient of friction than sliding coefficient. The sliders can be changed readily, but the design of the pendulum head requires considerable attention.

The Road Research Laboratory of England has developed a pendulum-type machine known as the British Portable Skid-Resistance Tester (Figure 3.). This tester is identical in principle with the NBS slipperiness tester. Considerable attention was given to construction details to insure that the apparatus would be quick and easy to use, and would maintain accuracy over long periods. The slider, which is spring loaded, is a three-inch by one-inch block of rubber that comes in contact with the suface along

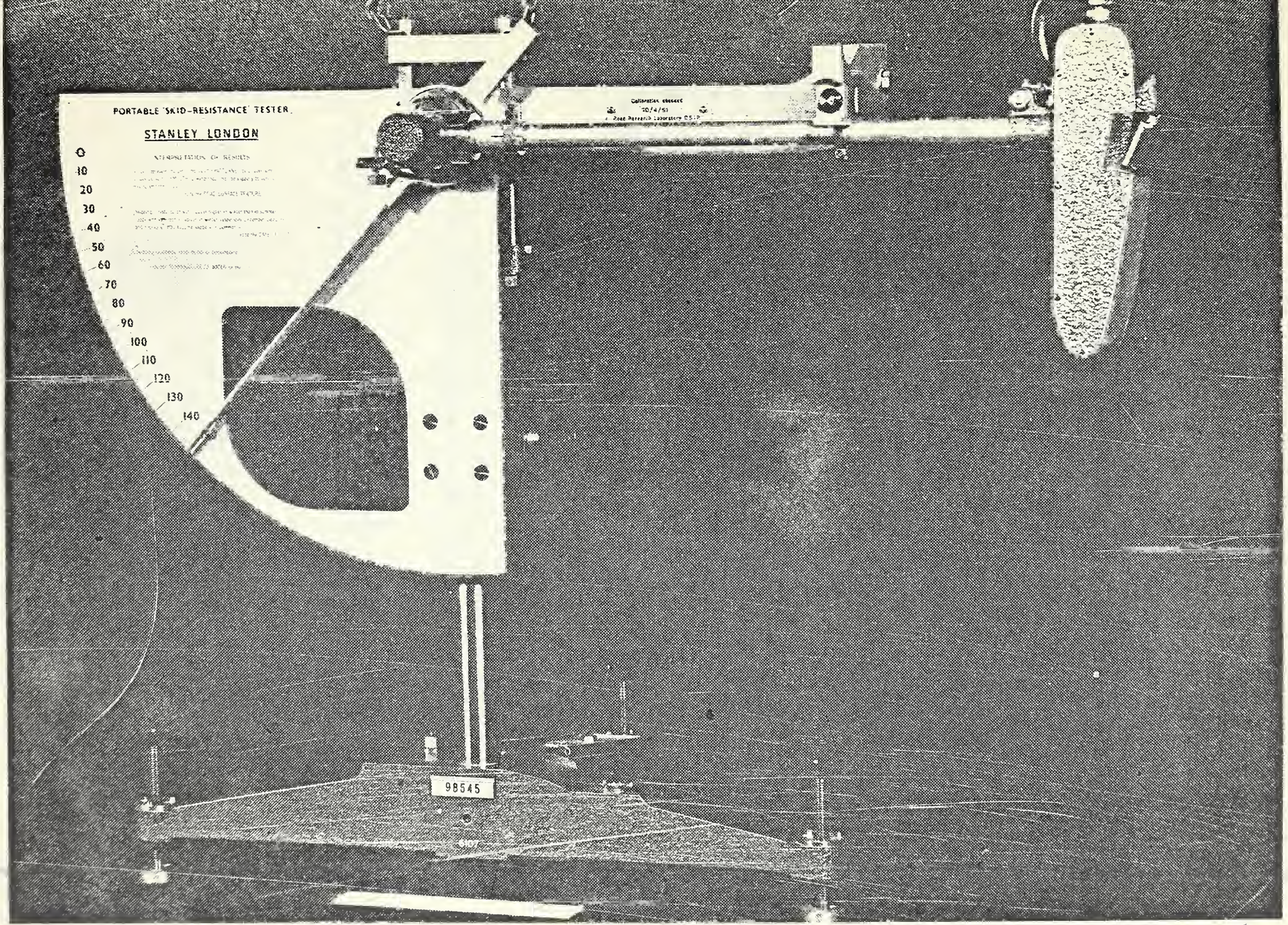

FIGURE 3. BRITISH PORTABLE SKID-RESISTANCE TESTER DEVELOPED BY THE ROAD RESEARCH LABORATORY OF ENGLAND.

one edge of the three-inch length. The machine can be adjusted vertically, so that the length of surface the slider traverses can be controlled. After the proper adjustments are made, the pendulum and a pointer (the pointer acts from the same axis as the pendulum) are cocked in a right-hand horizontal position. Upon release, the pendulum carries the pointer through an arc and falls away, leaving the pointer at the furthest point of the arc traversed by the pendulum. At this point, a measurement is recorded from a direct scale. The scale is numbered from 0 to 150, and the quantity measured is termed "skid resistance" by the British.

The British tester, like other pendulum testers, is built around the principle of the conservation of energy. This principle states that the energy of a system at given State 1 (E_1) minus the energy at State 2 (E_2) must equal energy lost (Er) when the system is brought from State 1 to State 2. See Figure 4.

In equation form:

$$Er = E_1 - E_2 \qquad (1)$$

In the present case, Er is the energy lost by the pendulum as the slider is dragged over the surface under test and is given by

$$Er = d \cdot F \qquad (2a)$$

where d is the sliding length and F is the resistance experienced by the slider over the sliding length d.

Since a coefficient of sliding friction can be defined by

$$\mu = F/P \qquad (3)$$

where P is the average pressure on vertical load with which the slider is pressed against the surface under test, equation 2a may be written as

$$Er = d\mu P \qquad (2b)$$

The energy at State 1 is the potential energy of the pendulum prior to release and is given by product (ignoring the force of gravity which is constant for a given location)

$$E_1 = ho \cdot W \qquad (4)$$

where ho is the height of the center of gravity (C.G) of the pendulum with

CONCEPT OF ENERGY CONSERVATION

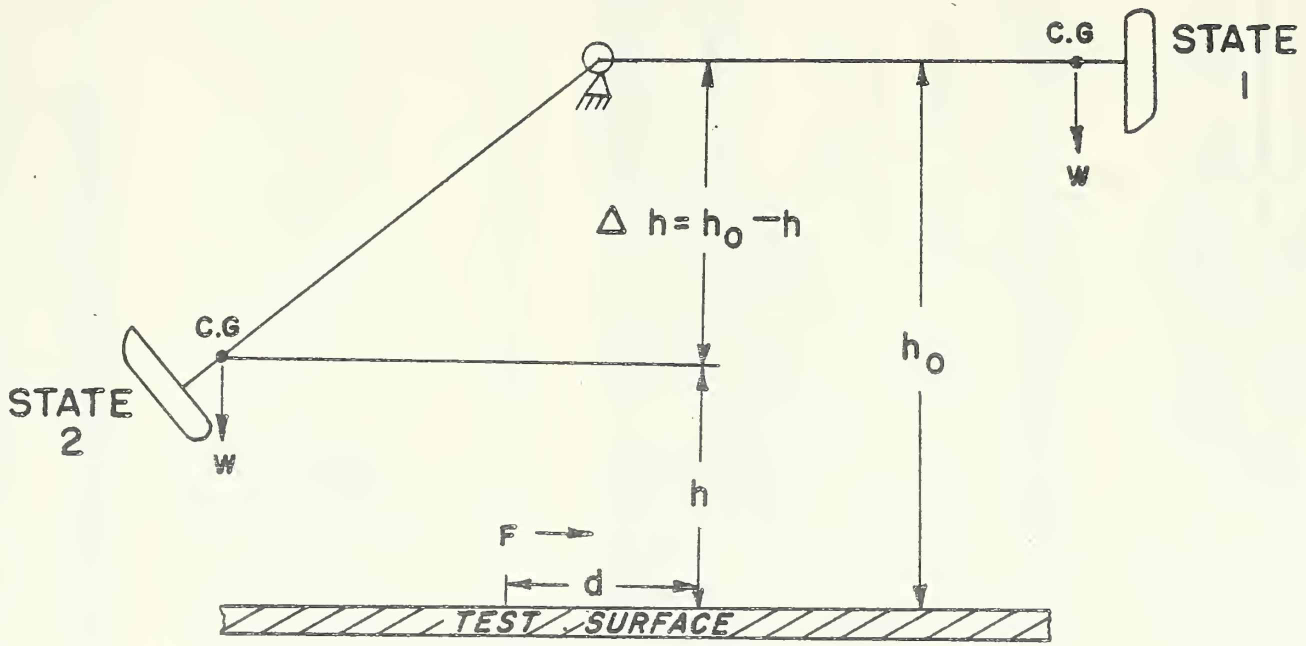

FIGURE 4. ILLUSTRATION OF THE PRINCIPLE OF CONSERVATION OF ENERGY BASED ON THE PENDULUM-TYPE SLIPPERINESS TESTER. STATE 1, WHERE $E_1 = h_o \cdot W$, MINUS STATE 2, WHERE $E_2 = h \cdot W$ WHEN THE SYSTEM IS BROUGHT FROM STATE 1 TO STATE 2, EQUALS LOST Er, WHERE $Er = d \cdot F$.

respect to an arbitrary reference plane (most conveniently the test surface) and W is the weight of the pendulum head which can be assumed to be concentrated in the C.G. The energy at State 2 is the potential energy of the pendulum after the slider has been dragged over the surface and is given by

$$E_2 = h \cdot W \qquad (5)$$

analogous to equation (4). Here h is the height of the C.G. with respect to the reference plane at the end of the pendulum swing; W having the same meaning as before.

When equations (2b), (4), and (5) are substituted into equation (1), one obtains

$$\mu = \frac{W(ho - h)}{dP} \qquad (6)$$

4. SELECTION OF RUBBER SLIDERS

A large number of slipperiness tests were conducted with the British pendulum tester on concrete surfaces and special laboratory constructed surfaces, using controlled natural rubber sliders provided by the British Road Research Laboratory and synthetic rubber sliders made of the formulation used by ASTM Committee E-17 for test tires.[1/]

[1/] <u>Oil Extended SBR Tread</u>

SBR 1712	137.50
Zinc Oxide	3.0
Stearic Acid	2.0
Sunproof wax	2.0
Sundex 53	4.0
ISAF	69.0
Sulfur	2.0
Santo Cure	1.1
Flexamine	1.5

Sheet Cure 60 Min. at 280°F-------------300% Modulus 1400 psi
Tire Tread - Hardness (Durometer-------57 ±2 Taken 24 Hours after Cure.

The specifications for this tire do not appear in an ASTM Standard at the present time. The tire was developed as a research tool in connection with the evaluation of road surfaces by Committee E-17 on Skid Resistance, whose objective is to develop standard methods of testing road surfaces for their non-skid properties and possibly to develop standard surfaces for use in this research. The tire was actually developed by the General Tire and Rubber Co., Akron, Ohio.

The results of these tests are shown in Figure 5. The plotted points represent the average of 15 readings taken at 3 different places on the concrete surfaces and an average of 10 readings taken at 2 different places on the laboratory constructed surfaces. It may be noted that most of the points fall below the line of equality indicating a difference in the two rubbers. In the area of a 40 to 50 scale reading, the values for synthetic rubber are approximately 20% greater than those observed with the natural rubber.

Results of Durometer Hardness tests reveal that there is a small but measurable difference (2 units) in the hardness of these two materials, with the synthetic rubber being the harder of the two, in tests made at temperatures of 30°F to 110°F. A 20% lower hysteresis loss of the natural as compared with the synthetic rubber was also noted.

Additional tests were made with seven British pendulum testers on five surfaces to compare the two rubber materials and to determine possible machine variables. The controls instituted in these tests were:

(1) Preconditioning the rubber sliders before testing by making 10 passes over silicon carbide surfaces with particle size grades of 50, 60, and 80.

(2) Setting the distance of contact of the rubber with the test surface at 5 ±1/16 inches.

(3) Making all tests under wet conditions, i.e. uniformly flooding the test surface between each test with water at 73 ±3°F.

(4) Testing within the same day at one location on the same surfaces.

The plotted points of the average of seven tests with each machine on the five surfaces are given in Figure 6. On most surfaces, the results give a high reading (more slip-resistance) with the synthetic rubber. The greatest difference between the values for the natural and synthetic rubber is shown on the epoxy surface, which has a pyramid surface design. This is believed to be caused by the difference in hysteresis of the two rubbers.

Table 1. lists the instruments, calibration dates, and results of the above control tests. The following conclusions may be drawn from this table:

(1) With the exception of the steel surface, the synthetic rubber sliders gave higher readings than the natural rubber sliders (as shown in Figure 6). On the steel surface, where the hysteresis and cohesive forces of the rubber were of less significance, the softer natural rubber with its greater surface contact gave higher results.

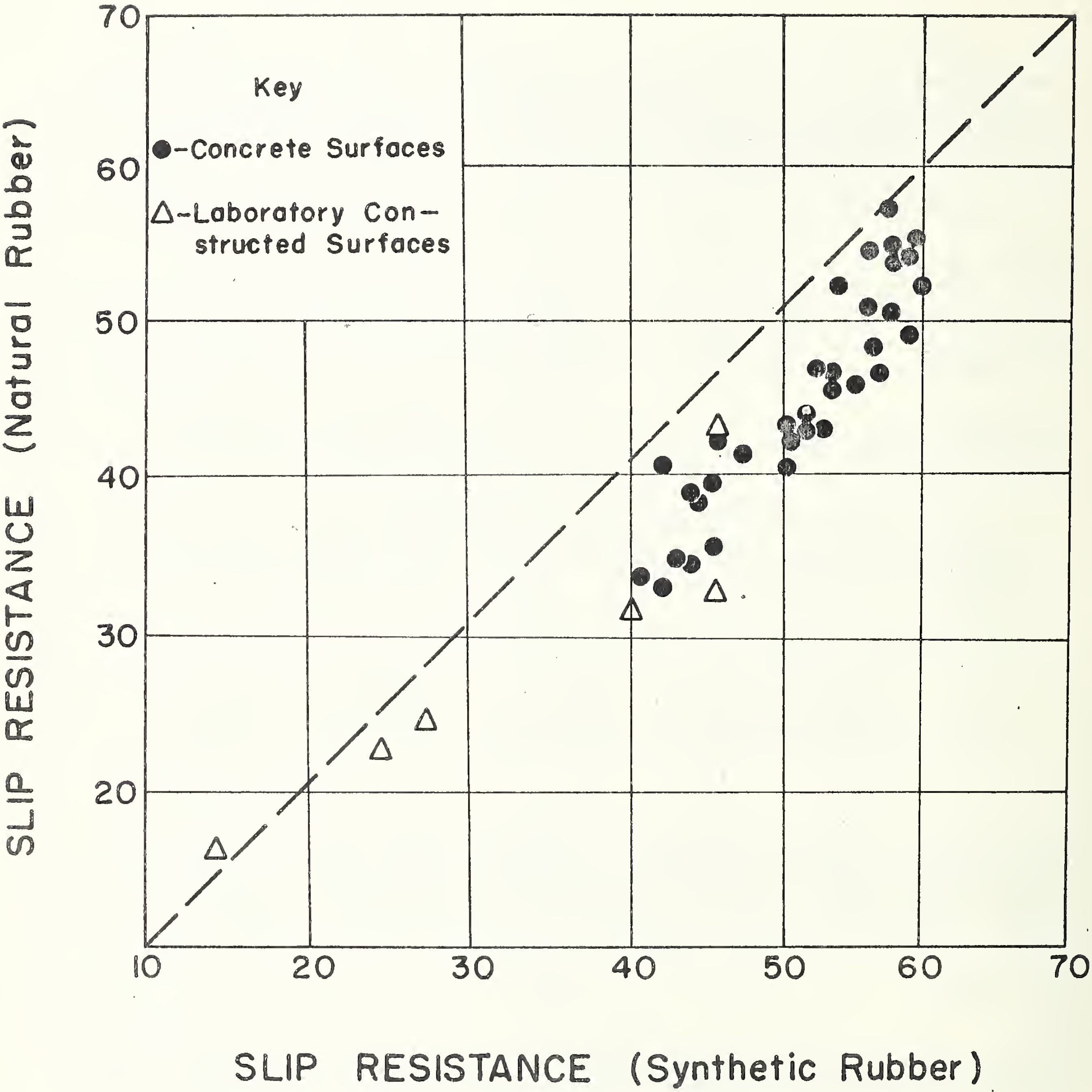

FIGURE 5. CORRELATION BETWEEN NATURAL AND SYNTHETIC RUBBER AS DETERMINED BY ONE BRITISH PENDULUM TESTER.

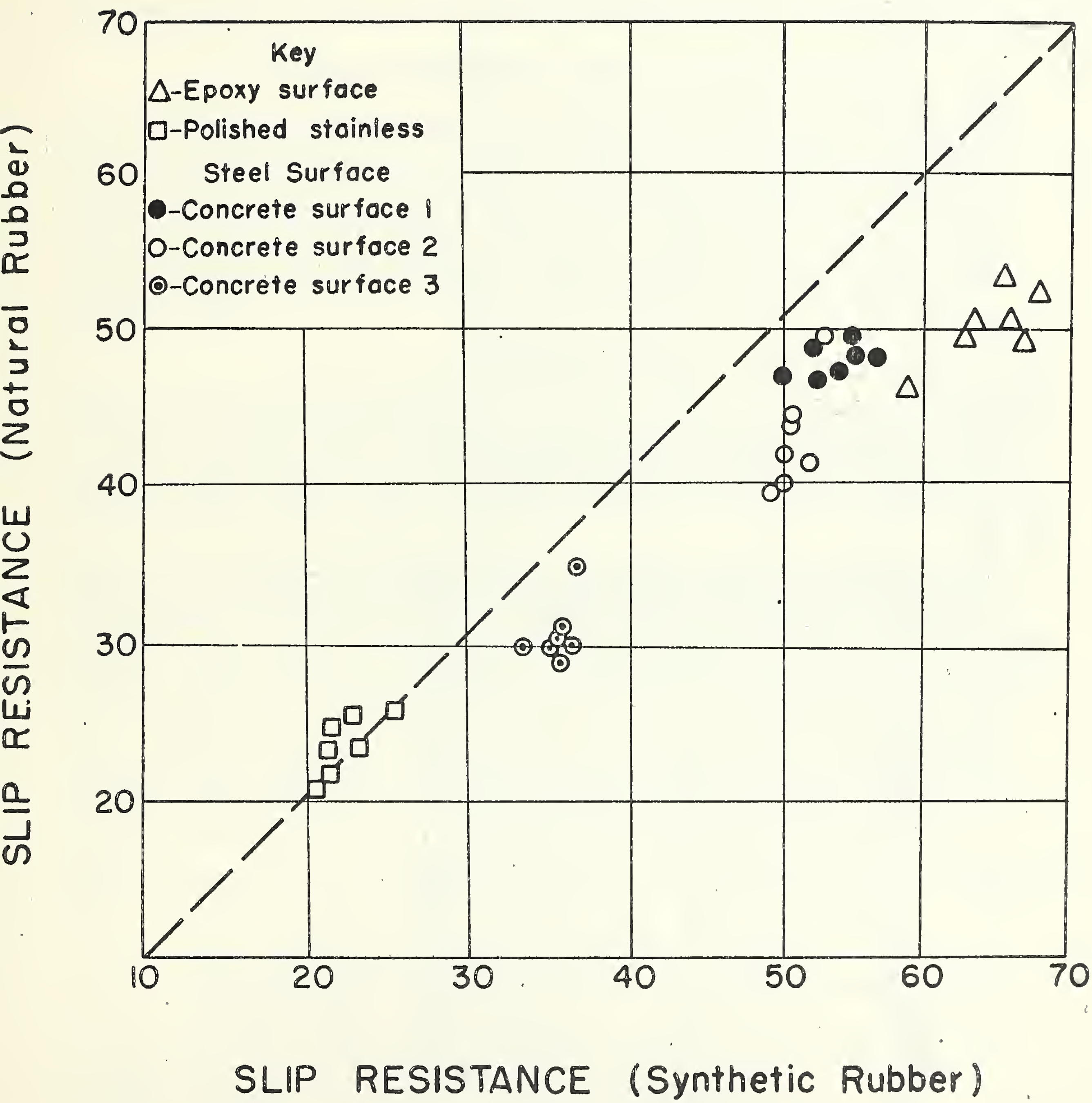

FIGURE 6. CORRELATION BETWEEN NATURAL AND SYNTHETIC RUBBER AS DETERMINED BY SEVEN BRITISH PENDULUM TESTERS.

TABLE 1. TABULATED RESULTS

Instrument Designation	No.	Calibration data 1/	Slip-resistance data under wet conditions: Epoxy		Steel		Concrete 1		Concrete 2		Concrete 3	
			N*	S*	N	S	N	S	N	S	N	S
Va.	6026	5-60	48	58	23	20	46	50	40	49	30	33
N. Y.	6141	9-61	51	63	23	22	48	54	42	52	31	35
B.P.R.	6120	4-61	52	68	25	24	47	53	44	50	32	35
N.C.S.A.	6140	10-61	49	67	25	20	49	55	42	50	30	36
N.S.A.	6136	10-61	50	62	25	20	47	53	49	52	31	35
Pa.	6139	10-61	50	66	24	20	45	56	40	50	29	36
N.B.S.	6107	4-61	53	64	25	21	48	54	44	50	35	38

1/ The date the instrument was calibrated by the Road Research Laboratory in England.

* N = natural rubber S = synthetic rubber

(2) Instrument No. 6026 gave consistently lower readings.

(3) No changes in the test surfaces were noted during the test.

5. RESULTS OF SLIPPERINESS TESTS ON FLOORING MATERIALS

To determine the suitability of the British pendulum tester for the evaluation of flooring materials, selected surfaces from different manufacturers were tested with the synthetic rubber slider (see Table 2). The samples of the walkway surfaces were tested both before and after four years exposure to pedestrian traffic. They were applied to one-inch plywood with adhesive. No floor surface treatment or finish was applied to the samples during exposure to traffic. Some samples, however, had a factory-applied finish.

6. REFERENCE SURFACES

Since the scope of this project is the preparation of reference surfaces, it seems evident that a reliable method of measuring the slip-resistance of these surfaces must be obtained and that the reference surfaces so developed must react toward the measuring device in the same manner as actual walkway and roadway surfaces.

Some of the variables which affect the results by the British Pendulum Tester have been discussed. All these testers give useful and valuable information, but they would be even more useful if correlated with some standard reference surface. When the instrument variables such as rubber slider, spring pressure, and method of operation are controlled, a more exacting study may be made on possible materials for reference surfaces.

Some materials have been investigated to a limited extent. These include epoxy surfaces with pyramid surface designs and polished stainless steel surfaces (see Table 1). Other surfaces such as different grades of silicon carbide cloth, ground glass, and canvas have also been tried.

The following desirable characteristics for reference surfaces are suggested:

1. Ease of reproduction.
2. Ease of shaping or obtaining geometric designs.
3. General magnitude of resistance (i.e. ability to withstand test conditions).
4. Surfaces within and including the range commonly experienced in walkway and roadways.
5. Suitable for laboratory use and handling.
6. [2] Materials of long-term stability and durability.

[2] Expendable materials with uniform, reproducible surfaces meeting the other listed characteristics are also suggested.

TABLE 2.

RESULTS OF SLIPPERINESS TESTS ON FLOORING MATERIALS

Sample	Dry			Wet		
	unexposed	exposed		unexposed	exposed	
		W/T 1/	A/T 1/		W/T 1/	A/T 1/
Asphalt Tile 1	120	67	72	35	27	24
Asphalt Tile 2	114	68	86	37	25	25
Asphalt Tile 3	88	66	84	38	35	34
Asphalt Tile 4 2/	45	69	70	30	32	38
Asphalt Tile 5	115	90	111	39	42	47
Asphalt Tile 6	108	87	107	26	39	36
Vinyl Asbestos Tile 1	98	89	114	40	37	41
Vinyl Asbestos Tile 2	109	100	108	42	41	34
Vinyl Asbestos Tile 3	95	54	92	28	29	27
Vinyl Asbestos Tile 4	73	56	70	31	29	23
Cork 2/	54	95	93	--	44	46
Linoleum	66	61	87	39	33	32
Cork/vinyl film	79	72	104	23	28	30
Vinyl	107	93	119	45	30	31

1/ W/T = with the traffic.
A/T = across the traffic.

2/ Factory-applied finish.

7. Relation with water

   a. wettability
   b. inert to water
   c. texture with respect to water.

7. REFERENCES

[1] Tabor, D., "Friction Between Tire and Road", Engineering 186: 838-840 (1958).

[2] Sigler, P. A., "Relative Slipperiness of Floor and Deck Surfaces", Building Materials and Structures Report, National Bureau of Standards, (July 1943), BMS-100.

[3] Sigler, P. A., Geib, M. N., and Boone, T. H., "Measurement of the Slipperiness of Walkway Surfaces, Journal of Research, National Bureau of Standards, Vol. 40, p. 339 (May 1948), RP1879.

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