DEPARTMENT OF COMMERCE * BUREAU OF STANDARDS

NBS TECHNICAL NOTE 953

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

A New Portable Tester for the Evaluation of the Slip-Resistance of Walkway Surfaces

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.

[2] Located at Boulder, Colorado 80302.

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Technical Note 953

Robert J. Brungraber

Center for Building Technology
Institute for Applied Technology
National Bureau of Standards
Washington, D.C. 20234

This paper was prepared by the author while he was an Intergovernmental Personnel Act Appointee in the Building Safety Section of the Center for Building Technology, on leave from Bucknell University, Lewisburg, Pennsylvania.

U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, Secretary

Dr. Sidney Harman, Under Secretary
Jordan J. Baruch, Assistant Secretary for Science and Technology

U.S. NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Acting Director

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A NEW PORTABLE TESTER FOR THE EVALUATION OF THE SLIP-RESISTANCE OF WALKWAY SURFACES

Robert J. Brungraber

The paper describes the available devices for testing the slip-resistance developed between walkway surfaces and shoe sole or heel materials. The limitations of available testers are detailed, and the need for a more reliable tester that can be used on actual floors under true field conditions, such as in the presence of water, is shown. The design and development of the new NBS-Brungraber Slip-Resistance Tester is described, including a discussion of the test programs that were employed to evaluate it.

Key words: Flooring; floor treatments; shoe sole and heel materials; slip-resistance tester; walkway surfaces; waxes and polishes.

A NEW PORTABLE TESTER FOR THE EVALUATION OF THE SLIP-RESISTANCE OF WALKWAY SURFACES

1. INTRODUCTION

The extensive and continued concern for injuries associated with the slipperiness of floor surfaces prompted the Building Safety Section of the National Bureau of Standards to initiate a research program for the development of an improved measurement technique (or device) that could lead to a national standard for the slip-resistance of walkway surfaces. At the outset of the study it was evident that in spite of many man-years of research and development, there was as yet no reliable device suitable for measuring the in-place slip-resistance of actual floors as related to human locomotion. The major portion of this study of the slip-resistance of floors, therefore, has been the development of such a tester. This report discusses the need for and describes the development of this device.

An earlier report by the author, entitled "An Overview of Floor Slip-Resistance Research With Annotated Bibliography" (NBS Technical Note 895, January 1976), reviews the extensive research related to the slip-resistance of floors. The present report makes extensive use of that bibliography. Each citation of the present report is made by an alphanumeric identifier which locates the reference in the annotated bibliography as well as in the reference list at the end of this report.

2. THE NEED FOR A PORTABLE SLIP-RESISTANCE TESTER

Slips and falls are a serious problem in homes as well as in public buildings. For example, the 1974 edition of "Accident Facts," published by the National Safety Council, indicated that annually 8 million falls occur in homes, resulting in 1.6 million disabling injuries and 9,600 deaths. The "Annotated Bibliography" referred to in the Introduction contains references citing accident statistics for department stores and farms, and describes the continuing research and development efforts of the floor wax and polish industry, the shoe manufacturers and buyers or specifiers, numerous Government laboratories and several representatives of the accident insurance establishment. More recently the swimming pool industry and the bathroom fixture industry, under the influence of the Consumer Product Safety Commission and working within the structure of the American Society for Testing and Materials, have initiated efforts which are expected to lead to the development of slip-resistance standards. In some cases, such as for shoes, a laboratory test might be satisfactory; however, most of the interest has been in a tester suitable for evaluating actual floors and floor treatments in the field.

The occurrence of slip is related to many factors, such as: the flooring material, particularly any surface treatment; the shoe material and its condition, new or worn, for example; the presence of contaminants such as water, dust, soap, banana peels, etc.; the condition of the walker, physical and mental; and the activity of the walker, walking, running, or performing athletics, etc. However, the only items that can be reasonably controlled are the floor surface and the shoe material. Certainly the significant parameter relating the effects of the floor and the shoe to the occurrence of slip is the coefficient of friction. This is a fundamental property which can be reliably reproduced and measured. However, it must be measured under circumstances representative of normal walking so that good correlation with accident occurrences can be expected.

A question of major importance in relating the coefficient of friction to the occurrence of slip is: which value is significant, the static (that value which must be exceeded to initiate motion) or the dynamic (that value at which motion will continue)? For most materials the static value is higher than the dynamic value. Kinesiological studies made at Berkeley (B-7)[1/] and in Sweden (C-10), as well as an analysis of

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[1/] These alphanumeric designations enclosed in parentheses refer to the reference list at the end of this paper.

motion pictures made at the National Bureau of Standards in the 1940s, indicate that no slip occurs between the shoe and the floor during normal walking. Thus, as has been concluded by several other investigators (A-2, A-3, D-3 and D-24), the present study accepts that in order for slip to occur during normal walking, the static coefficient of friction must be overcome.

Once slip does occur, for whatever reason, the dynamic coefficient of friction and more particularly the ratio of dynamic to static may very well become important. However, consideration of this would require a knowledge of the kinesiology and anthropometry during actual falls. One of the more effective ways to study kinesiology and anthropometry is by analyzing slow-motion pictures of the events of interest. However, it is difficult to simulate the impromptu feature of slips and falls by staging or to predict the location of accidental slips or falls in order to permit monitoring of their occurrence, so that slow-motion pictures of slips and falls are difficult to obtain. The Architectural Research Section in the Center for Building Technology of the National Bureau of Standards has had some success in recording accidental falls by photographing people movement in the vicinity of localized hazards such as stairs, landings and ramps. Nevertheless, this has only a limited relationship to slips on level floors since anthropometric studies have shown that for normal walking on stairs, for example, the requirements for coefficient of friction are considerably less than for walking on level floors. A good indication of the minimum value of coefficient of friction needed to permit safe walking is the maximum value of the tangent of the angle the leg makes with the vertical at any time the foot is in contact with the floor. For normal usage of stairs and ramps, it can be shown that there is less inclination of the leg than for walking on level surfaces.

Another important feature in the measurement of the coefficient of friction between floors and shoe sole or heel materials is the timing of the test. This is particularly important when time-dependent environmental conditions are to be considered. For example, if the effect of some time-dependent floor treatment or contaminant such as water or a banana peel is to be studied, the test must carefully reproduce the action of a human foot during normal walking. Specifically, the lateral (forward) or sliding load must be applied as soon as the vertical or normal force is applied so that adhesion, which could result in an unrealistically high coefficient of friction, will not have time to develop. During normal walking on wet surfaces, for example, there is likely to be a significant layer of water between the sole or heel and the floor so that fluid friction would be present, resulting in rather low values of coefficient of friction. If, however, the normal force is permitted to stand before the application of the lateral force, the water layer will be squeezed out leaving only a thin molecular layer of water, which has been shown to enhance the adhesion and thus increase the friction unrealistically. This phenomenon has been noted by others (D-3, D-15, D-20, D-23, D-34, E-3) and may very well explain the surprising but frequent finding that leather soles are more slip-resistant on wet surfaces than on dry surfaces.

3. LIMITATIONS OF EXISTING FLOOR SLIP-RESISTANCE TESTERS

Most of the methods currently used for the determination of floor slip-resistance have been thoroughly described elsewhere (Section D of NBS-TN 895) and summarized in References E-1 and E-3. They can best be considered in three categories:

(1) A drag type meter. This consists of a weight of known value, having a facing of a certain shoe sole or heel material, which can be drawn across a floor surface in such a way as to permit the measurement of the force needed to initiate motion (static friction) or to maintain motion (dynamic friction).

(2) A pendulum type meter. This consists of a pendulum, faced with a certain shoe sole or heel material, which can be adjusted to sweep a path across a flooring surface so that the contact pressure between the

facing and the floor follows a predetermined time-dependent pattern. The resulting loss of energy of the pendulum is claimed to be a measure of the dynamic friction.

(3) An articulated strut. This applies a known constant vertical force to a shoe faced with a certain sole or heel material and then applies an increasing lateral (forward) force until slip occurs. The ratio of lateral force at slip to the known vertical force is the static coefficient of friction. The vertical force is applied to the top of an articulated strut, to the bottom of which is attached the shoe. At the start of the test the articulated strut is vertical so that the shoe is subjected to a vertical load only. As the test progresses, the articulated strut is slowly inclined so that the shoe continues to be subjected to the constant vertical load, in addition to an increasing horizontal or tangential load, until slip occurs. The tangent of the angle that the articulated strut makes with respect to the vertical, at the instant of slip, is taken to be the ratio of the horizontal and vertical components of the force applied to the shoe and thus the static coefficient of friction.

Examples of the drag type meter are the Horizontal Pull Slipmeter (D-22), the TOPAKA (D-39), the Model 80 Floor Friction Tester (D-28) and more sophisticated devices such as that described by Braun and Roemer (D-3).[2/]

Some researchers claim that the drag type meter can measure both static and dynamic friction. However, Irvine, the developer of the Horizontal Pull Slipmeter, has found that the dynamic and static coefficients are both seriously influenced by the velocity at which the meter is pulled, and thus has found it necessary to supply a capstan-headed

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[2/] Certain commercial equipment, instruments or materials are identified in this paper in order to adequately specify the experimental procedure. In no case does this identification imply recommendation or endorsement by the National Bureau of Standards.

motor to pull the meter at a constant velocity. Even then, as has been demonstrated by Braun and Roemer (D-3), dynamic effects seriously influence both the static and the dynamic readings. The static reading is affected by the force required to accelerate the weight which supplies the normal load; and since this is the weight of the entire device, the error can be significant. In measuring the dynamic friction, the phenomenon of stick-slip frequently develops, resulting in cyclical variation of the value of the force needed to maintain motion, making it difficult to establish the true value. This has been found to be a function of the elasticity of the device, particularly portions of the prime mover such as the string of the capstan-headed motor of the Horizontal Pull Slipmeter and the TOPAKA. Another serious limitation of the drag type meter is the built-in but indeterminate time delay between the placement of the tester (application of the normal load) and the initiation of the test (application of the lateral load). This permits the thinning of any water layer and thus the enhancement of any adhesion tendencies. Test programs conducted with such meters (D-23, E-3) have frequently shown that the slip-resistance of leather soles is enhanced by the presence of water.

Most of the drag type meters (Horizontal Pull Slipmeter, TOPAKA, and Technical Products Tester) are portable, for use directly on a floor, and generally weigh about 10 lbs (44.5 N). The tester described by Braun and Roemer incorporates controls for the lateral motion as well as instrumentation for monitoring the lateral force and motion as functions of time. These items are permanent installations of their laboratory so that their tester is not portable and thus is not suitable for in situ testing of floors. In an attempt to achieve realistic contact pressures, while at the same time holding the weight to 10 lbs (44.5 n) or less, the Horizontal Pull Slipmeter and the Technical Products Tester use, as a sensor facing, three 1/2-in (12.7-mm) round buttons arranged in a triangular pattern. However, this causes mechanical interlocking on irregular flooring surfaces such as tile, flagstone, carpet, etc., and makes these testers unsuitable for such surfaces.

The pendulum type, as represented by the Sigler (D-34, D-35) and the British Portable Skid Tester (BPST) (D-16, D-21, D-36), measures the energy loss of the pendulum as an indirect indication of the dynamic friction. This makes the adjustment of this type of device quite critical; and thus, the conduct of a test quite laborious. Slow motion films of some BPST tests conducted at the National Bureau of Standards, as well as some tests made on bond paper over a sheet of carbon paper (D-25), show that the contact pressure varies erratically with time; consequently, it is difficult, if not impossible, to relate friction directly to the energy loss. The BPST has shown good correlation with the results of automotive skid tests, particularly on wet pavements, and does reveal the deleterious effects of water on the slip-resistance of sole and heel materials, simulating a 30-m/h (48.3-km/h) skid which is hardly representative of maneuvers of the feet that occur during normal walking.

Finally the articulated strut device, as represented by the James (D-24) and Hunter (D-20) Testers is based on the direct and fundamental principle of the resolution of forces. For both testers the "shoe" is 3 in (7.62 cm) square, resulting in an area of 9 sq in (58.1 sq cm), which was considered to be representative of the contact area of a typical foot or shoe. The Hunter device has the disadvantage that it measures the dynamic friction since the shoe is pulled across the floor until uncontrolled slip occurs, at which time the tangent of the resulting angle of the strut is measured. Thus the shoe is actually in motion when the measurement is taken. The James Tester does measure static friction; but for some reason not explained by James (D-24), the final version of this device is strictly a laboratory machine suitable only for evaluating flooring materials, not floors. Also, from his description of the device, tests could be made directly on floors with the initial design; but as is the case for the Hunter, the weight which provides the vertical force is 75-80 lbs (334-356 N) which makes the device portable only with difficulty. (Earlier a portable version of the Hunter Tester was developed by Gurney (D-18).)

Many investigators, including James, have shown that, within rather broad limits, the coefficient of friction, static or dynamic, between typical shoe and flooring materials is not sensitive to variations in contact pressure (D-20, D-24, D-38). This agrees with the basic laws of friction as first postulated by Coulomb (G-5) and Amontons (G-1). Thus, rather than the need to replicate the actual contact pressure between a human foot and the floor, it would seem that the provision by Hunter and James of such large surcharges (vertical weights) was for some other purpose, possibly to overcome the rather large internal friction that exists in the somewhat primitive bearings used in these devices. In fact, users of the James Tester have found it necessary to make numerous improvements and adjustments in order to get good repeatability for a single machine or good correlation among several machines. The abrupt falling of the heavy surcharge has been found to frequently knock the James Tester out of adjustment.

As is the case for the drag type tester, the James Tester also has a built-in, but generally indeterminate, time delay between the application of the normal load and the initiation of the horizontal or tangential loading. Particularly considering the magnitude of the normal load, 75-80 lbs (334-356 N), this delay aids the squeezing out of any fluid layer and thus encourages adhesion. Accordingly, the James Tester has also shown that moistening leather improves its slip-resistance. In fact, neither the James Tester nor the Horizontal Pull Slipmeter is recommended for other than dry conditions.

The James Tester and the test procedure using it (ASTM D-2047) have been developed extensively for many years by ASTM Committee D-21, Waxes and Polishes, and the members of the Waxes and Polishes Division of the Chemical Specialties Manufacturers' Association. Thus, it is, at present, the only slip-resistance test for floors that appears in an ASTM specification; and except for the fact that it is strictly a laboratory device suitable only for evaluating flooring materials, rather than floors, it appears to be a generally satisfactory device for the evaluation of flooring products and treatments and shoe sole and heel materials. The James Tester, as presently constructed, does require fairly continuous maintenance and readjustment, owing largely to the essentially uncontrolled descent of the 80-lb (356-N) surcharge; but this could be corrected by some fairly minor design modifications. Hence, the NBS development of a portable tester suitable for evaluating actual floors concentrated on using the same principles of operation as are used in the James Tester.

There have been many other testers developed over the years, but with the exception of a few unsuccessful attempts to create portable versions of the James Tester and some rather sophisticated versions of the drag type tester, most of the testers have been strictly intended for laboratory use. Most of these have been drag type testers wherein a sample of flooring has been dragged or rotated beneath a suitable weighted "shoe," which in turn was instrumented to measure the drag force.

Thus it was apparent that, in spite of the above described developments, there was still a need for yet another tester that: (a) could reliably measure a fundamental property, such as static coefficient of frictions, which is related to slip-resistance, (b) would be portable and thus suitable for the in situ evaluation of actual walkway surfaces, (c) could be easily modified to incorporate, as a sensor, a variety of materials representative of what people use on the bottoms of their feet, and (d) could be calibrated against a reliable standard.

4. DEVELOPMENT OF THE NBS-BRUNGRABER PORTABLE SLIP-RESISTANCE TESTER

A new portable slip-resistance tester has been developed. Two slightly different models of the new tester, shown in Figures 1 and 2, employ the same fundamental principle of the articulated strut as the James Tester. However, this design makes use of the fact that friction is not affected by the normal pressure and thus employs a surcharge of only approximately 13 lbs (57.8 N). The use of this smaller surcharge has been made possible by reducing internal friction by the use of low friction ball bushings at the several locations in the tester where relative translational displacements occur. The other major improvements incorporated in the new tester are: (1) The tester moves over the floor, rather than having the flooring moved under the tester, so that it is suitable for evaluating floors under true field conditions. (By the addition of a hinged plate to the bottom of the tester or by the use of a jig to retain the specimens, the tester can also be used to evaluate small flooring samples in the laboratory.) (2) The paper chart and pencil of the James Tester is replaced by a graduated rod that permits the direct reading of the static coefficient of friction. (3) The tester is self-actuated so that no power source is needed, and therefore there is no time delay between the application of the normal force and the iniiation of the application of the tangential force. Thus the tester successfully reveals the reduction in walking slip-resistance caused by the presence of a film of water. (4) The tester incorporates a shoe to which different sensor surfaces can be readily attached so that the tester can be easily modified to permit the evaluation of any material that is likely to be present on the bottom of human feet. (See Appendix A for a more detailed description of the NBS-Brungraber Tester and its operation.)

The NBS-Brungraber Portable Slip-Resistance Tester has been patented (U.S. Patent No. 3,975,940). The patent is the property of the U.S. Government and is available for license to any U.S. citizen or corporation.

During the development period, two models of the NBS-Brungraber Tester were built, the earlier model shown in Figure 1 and the later model shown in Figure 2. The earlier model (of which two examples were built), employs a single, splined vertical shaft, translating in a splined ball bushing, which effectively eliminates rotation of the vertical shaft while at the same time permitting unrestrained vertical translation. This design permitted the use of a variable number of circular weights as the surcharge. However, it was found that varying the surcharge did not vary the results significantly; and owing to the high cost and lack of

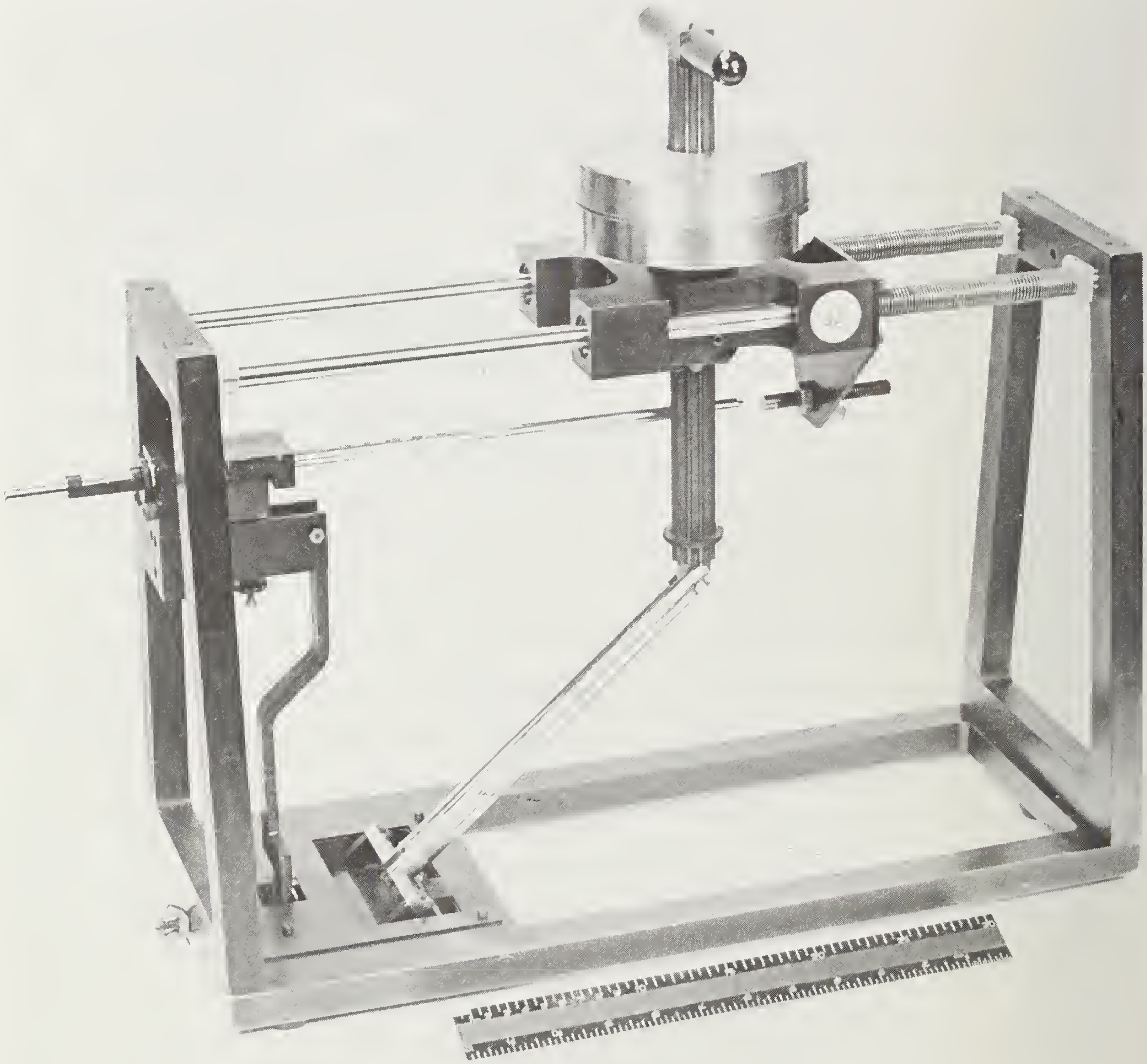


Fig. 1. Developmental Version of NBS-Brungraber Tester

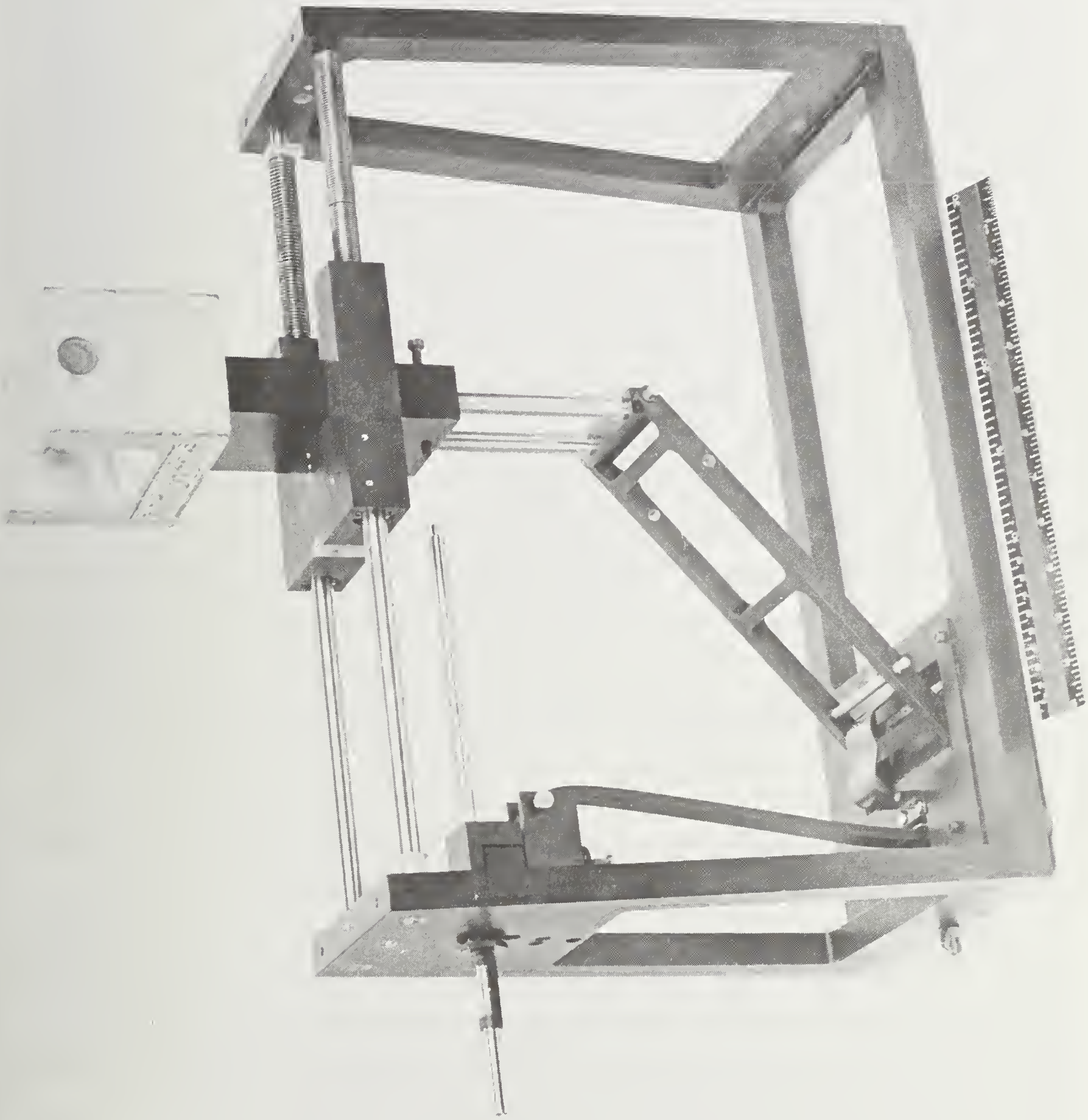


Fig. 2. Production Version of NBS-Brungraber Tester

general availability of the splined shaft/bushing assembly, a simpler and less expensive design, Figure 2, was developed.

In this design the single splined shaft was replaced by two smaller smooth shafts, identical to the ones used to provide lateral travel of the carriage, and the surcharge was provided by a single standard 10-lb (4.5-kg) weight which also incorporates the handle which is used to lift and operate the tester. This model has proven to be as effective and reliable as the earlier model.

A detailed description of the operation and maintenance of both models of the new tester is presented in the Appendix.

5. EVALUATION OF THE NEW TESTER

The new tester was evaluated in a series of test programs. The test programs were planned to determine the accuracy and reliability of the tester and also to provide answers to some additional questions of the slip-resistance problem as follows:

(1) Is there a material more suitable than natural leather for use as a facing material on the sensor of the tester?

(2) Is there a method, other than sanding, that can be used to clean and recondition the sensor facing material between tests?

(3) Is there some way to increase contact pressure between the sensor and the floor, other than by increasing the surcharge weights? Some researchers of the slip-resistance problem have judged it essential to replicate typical walking contact pressures in a tester and have either used large weights on a large sensor, as in the James Tester, or smaller weights on a small sensor, as in the Horizontal Pull Slipmeter.

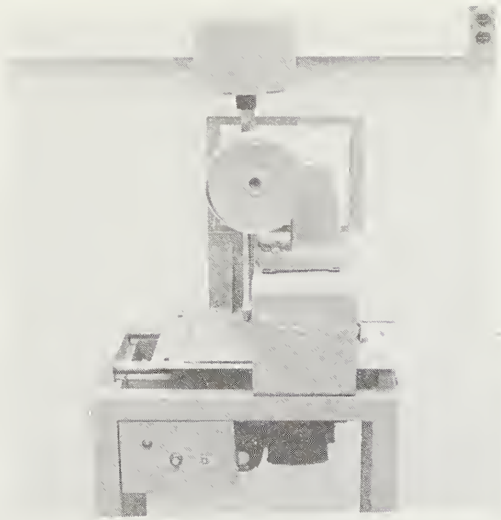
All the test programs were conducted in a laboratory in which the temperature and relative humidity were controlled by the general heating and ventilating system of the National Bureau of Standards. The temperature and relative humidity were continuously monitored by a device capable of measuring $\pm$ 2° F ($\pm$ 1° C) and $\pm$ 2% r.h. These measurements indicated that throughout the test programs the temperature was 72° $\pm$ 5° F (22° $\pm$ 3° C) and during all but the summer months, the relative humidity was 37% $\pm$ 5%, with occasional day-long excursions to 50% and very rare occurrences of as much as 62%. During the summer months the relative humidity was frequently as high as 70% $\pm$ 2%. Comparative tests were generally run on the same day as closely together as conveniently possible, so that atmospheric variation would be minimal, and thus not a significant factor in the study.

5.1. Pilot Test Program

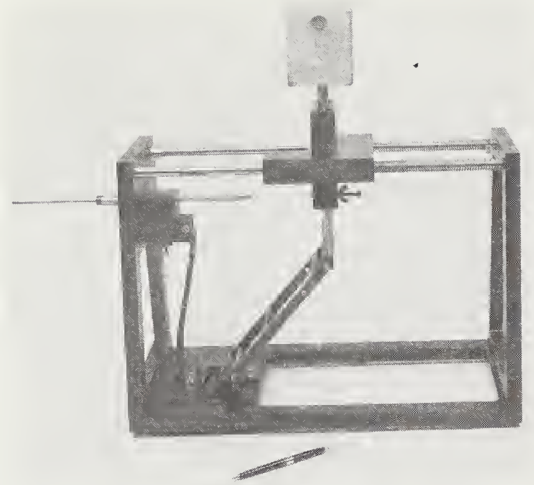
The first program for the evaluation of the new tester consisted of the comparison of four testers: the James Tester, the NBS-Brungraber Tester, the Horizontal Pull Slipmeter, and the Technical Products Tester (a less sophisticated version of the Horizontal Pull Slipmeter). The four testers are shown in Figure 3. All of these testers are claimed tc measure the static coefficient of friction, and it was on this basis that they were compared. The results from this testing program are presented in Figure 4.

Three other variables were examined: (1) two different floor surfaces, vinyl asbestos tile, waxed or bare; (2) four different facing materials for the sensing element of the tester, natural leather, a reconstituted leather, a standard liner--smooth side out, and the same standard liner--rough side out; (3) and two different methods of reconditioning the facing material between tests of different floor surfaces, sanding or washing with acetone.

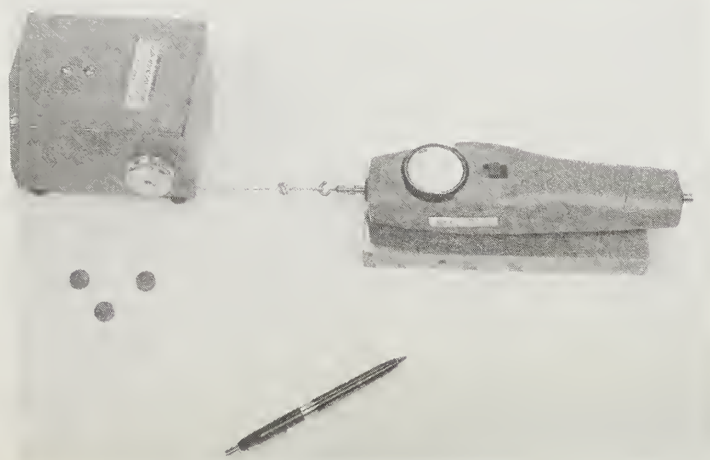
The 9 in x 9 in (23 cm x 23 cm) vinyl asbestos floor tiles were prepared in accordance with ASTM D 2047 "Standard Method of Test for Static Coefficient of Friction of Polish Coated Floor Surfaces as Measured by the James Machine," using method D of ASTM D 1436 "Standard Methods for



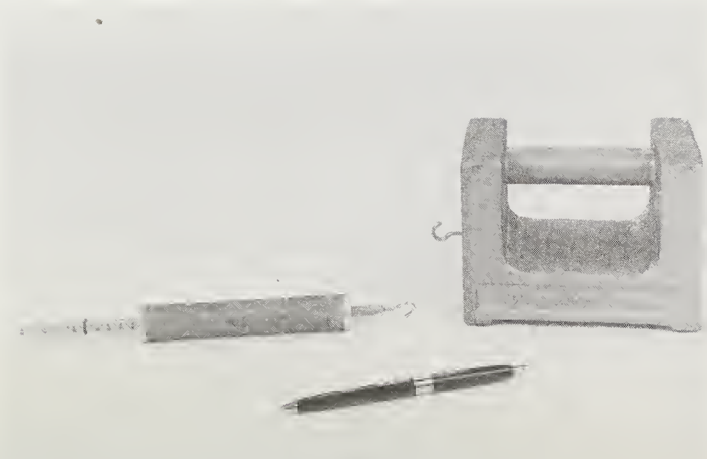
(a) James Tester



(b) NBS - Brungraber Tester



(c) Horizontal Pull Slipmeter



(d) Technical Products Tester

Fig. 3. Four Testers used for Comparative Evaluation

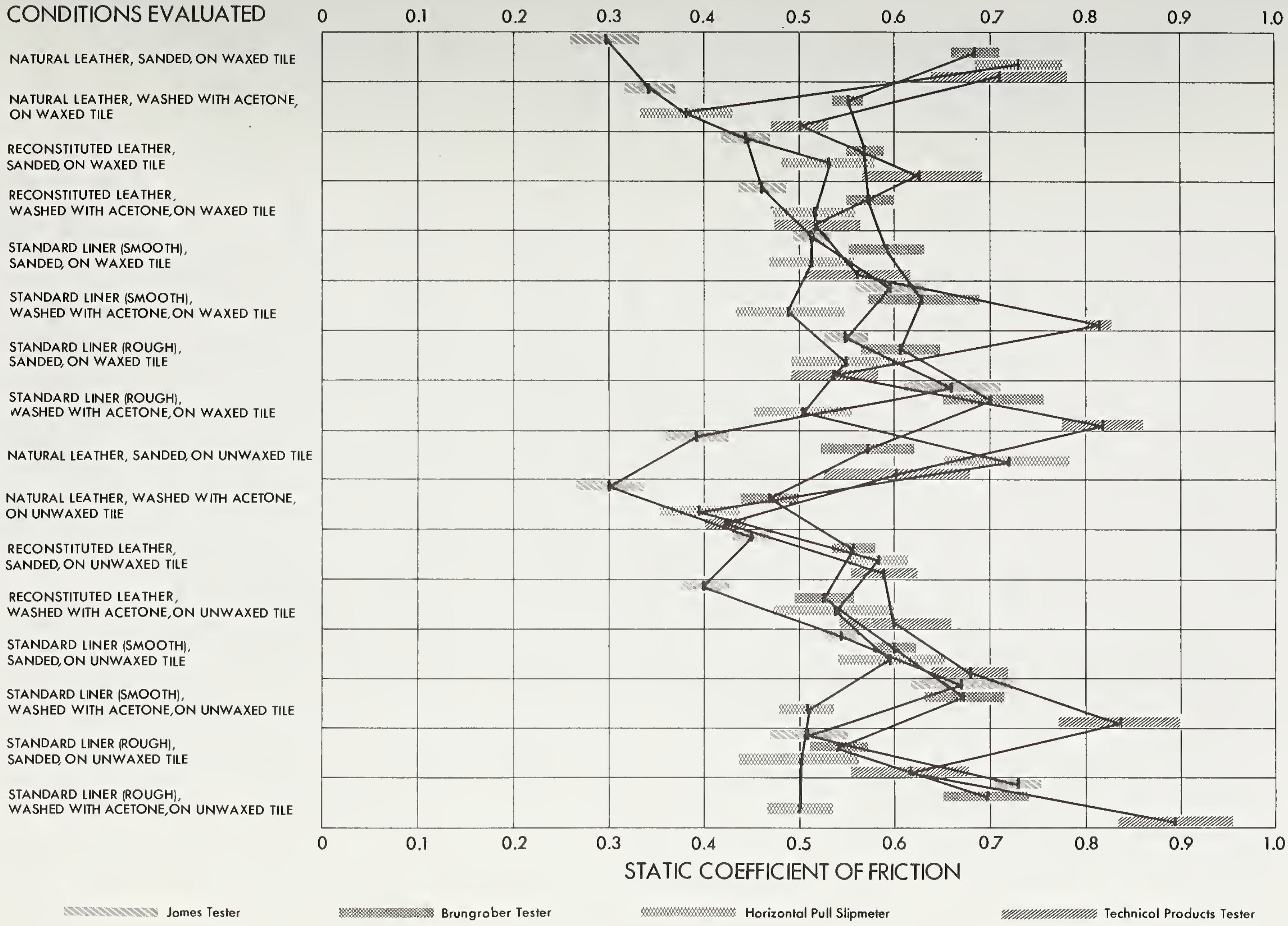


Fig. 4. Comparison of Floor Slip-Resistance Test Results

Application of Emulsion Floor Polishes to Substrates for Testing Purposes." As specified in ASTM Test Method D 2047, all the tiles had 10 coats of polish applied and removed or stripped, and the waxed tiles in addition had two more coats of wax applied. The Wax-Stripper System was an industrial product (not marketed retail) used to maintain the floors of the National Bureau of Standards' facilities at Gaithersburg, Maryland.

The purpose of evaluating four facing materials was to see whether or not one could be found that would yield more consistent results than the currently most popular test facing, 100% cowhide. Of the four facing materials, the leather was 100% cowhide sanded to a smooth flat surface; the reconstituted leather was a product made by shredding natural leather and then recombining the leather shreds with a urethane resin; and the standard liner (tested in two configurations) was a synthetic product manufactured for the express purpose of evaluating adhesives used in the manufacture of shoes. For this reason, this material has been produced under strict physical and chemical control for about 5 years and is likely to continue to be so produced. This standard liner material is furnished with a smooth side similar to that of a new leather sole and a rough side that has an appearance such as might result from sanding with about 200-grit sandpaper. Both sides were evaluated.

The two methods used to recondition the facing materials were: sanding with 400-grit sandpaper, as specified in D 2047, and washing with acetone. This second method was introduced because on the new tester it was found that it was difficult to remove the facing material for sanding. A later development incorporated in the models shown in Figures 1 and 2, consisting of a magnetically held clip for the facing materials, removed this constraint and made it possible to continue the general practice of sanding the facing material.

For each set of conditions, 12 test replications were performed in accordance with ASTM D 2047. The results of the program are plotted in Figure 3. In each case, the average is shown by a dark line surrounded by a distinctively cross-hatched bar extending one standard deviation in each direction from the mean. The cross-hatching differentiates the four testers used, and in addition, four lines are used to connect the means for each of the four testers.

The preliminary series of tests was intended merely as a guide for later test programs and thus was not subjected to a thorough statistical analysis. However, from consideration of the trends shown by the four lines, several conclusions were drawn and the later development and evaluations of the new tester were thereby guided.

5.1.1. Summary of Results

(1) With one exception (natural leather, sanded, on waxed tile), the new tester and the James Tester yielded similar indications of slip-resistance for the various combinations tested. That is, for 15 of the 16 conditions tested, the two testers would similarly rank the materials as to slip-resistance. In contrast, both the Horizontal Pull Slipmeter and the Technical Products Tester frequently varied considerably from either the NBS-Brungraber or the James Tester. That is, for 5 of the 16 conditions tested, either one or both of these testers would have ranked the materials quite differently than the NBS-Brungraber and James Tester. Based on these results and in consideration of the James Tester being recognized as an ASTM standard, it was decided to base further evaluation of the NBS-Brungraber Tester upon comparison with the James tester.

(2) The reconstituted leather is revealed as the most consistent material to use as facing for the sensor. For all four cases in which this material was used, all four of the testers agreed within 0.2 units of coefficient of friction; and for the new tester and the James, the agreement was within 0.1 units of coefficient of friction. Also, in these four cases for the new tester and the James, the precision was good, the standard deviation never exceeding 0.03. A standard deviation of 0.03 units of coefficient of friction would likely be adequate for evaluating

the slip-resistance of walkway surfaces, since the attainment of this precision would assure (with a probability of 99.73%) that a tester would determine values of coefficient of friction within $\pm$ 0.09 units of the average. For conditions as difficult to control and as subject to variation as the slip-resistance of floors, such precision is believed to be adequate.

(3) Reconditioning the facing material by washing with acetone can introduce considerable variation, particularly for the natural leather. However, when used with the reconstituted leather, the acetone appears to be satisfactory. This agrees with the findings of another series of tests wherein the NBS-Brungraber Tester was used with a sensor consisting of three 1/2-in (12.7-mm) round buttons similar to those used on the Horizontal Pull Slipmeter. In this series of tests the same four facing materials (natural leather, reconstituted leather, and standard liner, rough and smooth) were evaluated and in addition to sanding and washing with acetone, other reconditioning solvents (methyl ethyl ketone, benzene, and chloroform) were considered. This series of tests demonstrated that the 1/2-in (12.7-mm) round buttons could be successfully used on the NBS-Brungraber Tester if higher contact pressures were needed. However, in order to have the new tester more closely relate to the ASTM standard and to permit it to be adaptable to a greater variety of surfaces, such as swimming pool decks, etc., it was decided to concentrate the evaluation on the 3-in (7.62-cm) square sensor. The results of this same series of tests also confirmed the previous finding that the reconstituted leather was the most consistent material to use as a sensor.

(4) Although the new tester and the James Tester generally ranked the materials similarly, the NBS-Brunhraber Tester displayed a systematic positive deviation from the James Tester, with one exception: using the standard liner (rough), washed with acetone, on unwashed tile, the James Tester yielded lower values of coefficient of friction. This prompted a further study of the NBS-Brungraber Tester revealing that for accurate measurements, particularly for lower values of coefficient of friction, the

trigger of the tester had to be adjusted so as to permit not more than 1/8 in (3.17 mm) of free travel.

5.2. Second Test Program

A second program of tests was conducted to permit the comparison of the new tester and the James Tester over a wider range of values of coefficient of friction. For this series the test results as well as the results of a statistical analysis (t-test) are presented in Table 1. A description of the specimens and the test conditions is given in the headings and the notes of the table. In this series of tests there were 4 different sensor facings, 2 different floor surfaces and 2 different sensor treatments for a total of 16 different sets of conditions.

The t-test permits the systematic comparison of two test devices to ascertain whether or not they are giving the same results. In the conduct of a t-test a value of α, the significance level, is chosen. For these tests an α of 5% was selected as being a value that is frequently employed for such tests. The value of α, the significance level, is the chance one is willing to accept that a difference will be noted between the two testers when in fact there is no difference.

In 11 of the 16 cases the t-test indicates a significant difference between the testers. The precision of the NBS-Brungraber Tester is considerably better than that of the James in that in 12 of the 16 cases (a, b, c, e, f, h, i, j, k, l, m, and o), the standard deviation for the James Tester is greater than 0.03 while for the NBS-Brungraber Tester in only one case (h) is this value exceeded. As discussed with respect to the first set of tests, a standard deviation of 0.03 or less is considered acceptable for a device intended to measure the static coefficient of friction between shoes and walkway surfaces.

Table 1. Statistical Analysis (t-test) of Data:

Comparing the NBS-Brungraber Tester [1],[4] with the James Tester

(The Second Series of Tests)

SENSOR FACING	PARAMETER	FLOOR SURFACE			
		Waxed Vinyl Asbestos Floor Tile		Unwaxed Vinyl Asbestos Floor Tile	
		Sanded	Washed with Acetone	Sanded	Washed with Acetone
Natural Leather	T° F	74 [(a)] [(5)]	74 [(b)]	75 [(c)]	74 [(d)]
	rh %	48	42	34	42
	$\bar{X}_J$ (2)	0.372	0.313	0.345	0.278
	$\bar{X}_B$	0.430	0.413	0.461	0.340
	S_J (3)	0.079	0.055	0.051	0.016
	S_B	0.012	0.009	0.019	0.011
	U, (α=0.05)(6)	0.051	0.035	0.034	0.012
	$\bar{X}_J - \bar{X}_B$	-0.058*	-0.100*	-0.116*	-0.062*
Reconstituted Leather	T° F	74 [(e)]	73 [(f)]	74 [(g)]	73 [(h)]
	rh %	46	42	46	42
	$\bar{X}_J$	0.548	0.477	0.455	0.491
	$\bar{X}_B$	0.518	0.463	0.505	0.413
	S_J	0.045	0.049	0.026	0.081
	S_B	0.010	0.007	0.016	0.038
	U, (α=0.05)	0.029	0.031	0.020	0.057
	$\bar{X}_J - \bar{X}_B$	+0.030*	+0.014	-0.050*	+0.078*
Standard Liner (Smooth Side In Contact with Floor)	T° F	74 [(i)]	73 [(j)]	74 [(k)]	73 [(l)]
	rh %	57	50	57	50
	$\bar{X}_J$	0.462	0.468	0.426	0.507
	$\bar{X}_B$	0.456	0.480	0.545	0.479
	S_J	0.039	0.031	0.043	0.045
	S_B	0.023	0.017	0.028	0.019
	U, (α=0.05)	0.029	0.023	0.033	0.031
	$\bar{X}_J - \bar{X}_B$	+0.006	-0.012	-0.119*	+0.028
Standard Liner (Rough Side In Contact with Floor)	T° F	74 [(m)]	74 [(n)]	74 [(o)]	74 [(p)]
	rh %	43	42	43	42
	$\bar{X}_J$	0.458	0.543	0.446	0.583
	$\bar{X}_B$	0.405	0.566	0.461	0.711
	S_J	0.062	0.027	0.042	0.029
	S_B	0.018	0.022	0.019	0.017
	U, (α=0.05)	0.041	0.023	0.029	0.021
	$\bar{X}_J - \bar{X}_B$	+0.053*	+0.053*	-0.015	-0.128*

Table 1. Statistical Analysis (t-test) of Data (cont'd)

NOTES:

(1) For all cases the number of observations with the James Tester, N_J, was 12 and for the NBS-Brungraber Tester, N_B, was 8.

(2) $\overline{X}$ indicates the average, J for the James Tester and B for the NBS-Brungraber Tester.

(3) S indicates the standard deviation, J for James and B for NBS-Brungraber.

(4) The method used for the t-test was case 2, page 3-26 of Experimental Statistics, M. G. Natrella, Handbook 91, U.S. Dept. of Commerce, National Bureau of Standards, August 1963.

Case 2 was used because there were different numbers of measurements for the two testers, and the variability was believed to be different for the two testers.

(5) The lower case letters appearing near the temperature entry for each condition are used to identify the condition discussed in the text.

(6) U is the critical value for $| \overline{X}_J - \overline{X}_B |$; larger differences are significant and are indicated by an asterisk.

5.3. Third Test Program

A third series of tests was conducted to consider a greater variety of surfaces and conditions, some of which would result in very low values of static coefficient of friction. Again only the James Tester was compared with the new tester. The results of this series, along with results of the t-test, are presented in Table 2. A description of the specimens and the test conditions is given in the headings and the notes of the table. In this series of tests there were 10 different surfaces and 3 different test conditions resulting in 30 distinct combinations. All tests were conducted using a 100% natural cowhide sensor facing. Another purpose of the test program was to study the effectiveness of natural cowhide as a sensor facing to simulate the bare skin on a human foot when in contact with representative bathroom walkway surfaces.

Considering the results of the t-test it can be seen that in 14 of the 30 cases (c, e, f, i, k, m, p, r, t, w, y, z, cc & dd) $| \overline{X}_J - \overline{X}_B | > U$ indicating that the two devices are not giving the same results. For the wet conditions, the James Tester was in every case higher, although the difference was not always significant at the 5% level. In three cases, (1) the 1-in (25-mm) square ceramic tiles, wet; (2) the 3/4-in (19-mm) round dots, wet; and (3) the textured porcelain enameled tub, soapy; the difference between the results for the James Tester and the NBS-Brungraber Tester were highly significant. The James Tester indicated that the static coefficient of friction, and thus the implied slip-resistance, was nearly twice (for the soapy tub, more than twice) that indicated by the NBS-Brungraber Tester. This is a demonstration of the adhesion that can develop on wet surfaces if there is time for the intervening liquid to be squeezed out. Since in normal walking there is little if any time delay between the application of the normal load and the initiation of lateral loading such adhesion is unlikely to develop. It is believed the NBS-Brungraber Tester with its brief and controlled time delay more closely approximates the action of normal walking, and thus more closely estimates the true slip-resistance of moistened surfaces.

TABLE 2

STATISTICAL ANALYSIS (t-test) OF DATA

Comparing the NBS-Brungraber Tester
with the James Tester

(The Third Series of Tests)[1]

FLOOR SURFACE	PARAMETER	TEST CONDITIONS Dry	Wet (4)	Soapy (5)
Vinyl	$\overline{X}_J$ (2)	0.642 (a)	0.224 (b)	0.040 (c)
Asbestos	$\overline{X}_B$	0.640 (10)	0.174	0.092
Tile	S_J (3)	0.037	0.029	0.026
Waxed	S_B	0.040	0.061	0.008
	$U, (\alpha = 0.05)$ (13)	0.056	0.069	0.029
	$\overline{X}_J - \overline{X}_B$	+0.002	+0.050	-0.052*
Smooth	$\overline{X}_J$	0.640 (d)	0.262 (e)	0.074 (f)
Porcelain	$\overline{X}_B$	0.684	0.176	0.104
Enameled	S_J	0.152	0.026	0.009
Steel	S_B	0.068	0.077	0.009
Tub (6)	$U, (\alpha = 0.05)$	0.172	0.084	0.013
	$\overline{X}_J - \overline{X}_B$	-0.044	+0.086*	-0.030*
Textured	$\overline{X}_J$	1.000 (12)(g)	0.784 (h)	0.690 (i)
Porcelain	$\overline{X}_B$	1.000 (12)	0.708	0.184
Enameled	S_J	~ 0	0.101	0.128
Steel	S_B	~ 0	0.066	0.026
Tub (6)	$U, (\alpha = 0.05)$	~ 0	0.125	0.135
	$\overline{X}_J - \overline{X}_B$	~ 0	+0.076	+0.506*
Smooth	$\overline{X}_J$	0.414 (j)	0.280 (k)	0.100 (l)
Porcelain	$\overline{X}_B$	0.434	0.210	0.096
Enameled	S_J	0.063	0.055	0.024
Cast Iron	S_B	0.030	0.035	0.011
Tub (6)	$U, (\alpha = 0.05)$	0.072	0.067	0.027
	$\overline{X}_J - \overline{X}_B$	-0.020	+0.070*	+0.004
Textured	$\overline{X}_J$	0.490 (m)	0.334 (n)	0.100 (o)
Porcelain	$\overline{X}_B$	0.594	0.290	0.118
Enameled	S_J	0.085	0.065	0.021
Cast Iron	S_B	0.025	0.016	0.015
Tub (6)	$U, (\alpha = 0.05)$	0.091	0.069	0.027
	$\overline{X}_J - \overline{X}_B$	-0.104*	+0.044	-0.018

TABLE 2

(continued)

STATISTICAL ANALYSIS (t-test) OF DATA

FLOOR SURFACE	PARAMETER	TEST CONDITIONS: Dry	Wet (4)	Soapy (5)
Textured Fiberglass Reinforced Plastic Shower Base (6)	$\overline{X}_J$	0.528 (p)	0.992 (q)	0.882 (r)
	$\overline{X}_B$	0.598	0.960	0.774
	S_J	0.031	0.046	0.036
	S_B	0.054	0.020	0.088
	$U, (\alpha = 0.05)$	0.065	0.052	0.099
	$\overline{X}_J - \overline{X}_B$	-0.070*	+0.032	+0.108*
Quarry Tiles With Closed Joints Between Tiles (7)	$\overline{X}_J$	0.922 (s)	0.580 (t)	0.164 (u)
	$\overline{X}_B$	0.878	0.508	0.178
	S_J	0.082	0.043	0.024
	S_B	0.031	0.034	0.057
	$U, (\alpha = 0.05)$	0.091	0.057	0.064
	$\overline{X}_J - \overline{X}_B$	+0.044	+0.072*	-0.014
1-in (25-mm) Square Ceramic Tiles With Open, Grouted Joints (7)	$\overline{X}_J$	0.676 (v)	0.804 (w)	0.204 (x)
	$\overline{X}_B$	0.744	0.478	0.184
	S_J	0.053	0.021	0.035
	S_B	0.040	0.019	0.031
	$U, (\alpha = 0.05)$	0.069	0.029	0.048
	$\overline{X}_J - \overline{X}_B$	-0.068	+0.326*	+0.020
3/4-in (19-mm) Round Vinyl Dots Applied To An Acrylic Sheet (8)	$\overline{X}_J$	0.664 (y)	0.842 (z)	0.180 (aa)
	$\overline{X}_B$	0.732	0.536	0.200
	S_J	0.052	0.033	0.019
	S_B	0.013	0.041	0.048
	$U, (\alpha = 0.05)$	0.055	0.054	0.053
	$\overline{X}_J - \overline{X}_B$	-0.068*	+0.306*	+0.020
3/8-in (10-mm) Round Dots Molded Into A Vinyl Sheet (8)	$\overline{X}_J$	0.548 (bb)	0.958 (cc)	0.724 (dd)
	$\overline{X}_B$	0.576	0.916	0.572
	S_J	0.022	0.018	0.063
	S_B	0.034	0.023	0.103
	$U, (\alpha = 0.05)$	0.042	0.030	0.124
	$\overline{X}_J - \overline{X}_B$	-0.028	+0.042*	+0.152*

Table 2. Statistical Analysis (t-test) of Data (continued)

NOTES:

(1) For all cases the number of observations for either tester, N_J or N_B, was 5.

(2) $\overline{X}$ indicates the average, J for the James tester and B for the NBS-Brungraber tester.

(3) S indicates the standard deviation, J for James and B for NBS-Brungraber.

(4) The wet condition was both surface and sensor thoroughly wet with distilled water at room conditions, T = 71° ± 2° F (22° ± 1° C) and rh = 70% ± 2%.

(5) The soapy condition was both surface and sensor thoroughly wet with a 16% mixture by weight of a white liquid soap and distilled water.

(6) Supplied, as a gift, by U.S. Plumbing Products Division of American Standard Inc.

(7) Supplied by Tile Council of America.

(8) Supplied by Paul Kollsman, the developer.

(9) The method used for the t-test was case 1, page 3-23 of Experimental Statistics, M.G. Natrella, Handbook 91, U.S. Dept. of Commerce, National Bureau of Standards. Case 1 was used because the number of measurements for each tester was the same (See pages 3-29 of Natrella's book).

(10) The lower case identifiers in the top entry for each condition are used to identify the conditions in the discussion in the text.

(11) In all cases the sensor facing was 100% natural cowhide, reconditioned by sanding with 400-grit sandpaper.

(12) For this material both testers failed to slip, indicating that the static coefficient of friction was greater than 1.0.

(13) U is the critical value for $|\overline{X}_J - \overline{X}_B|$; larger differences are significant and are indicated by an asterisk.

Considering the standard deviations it can be seen that in 17 cases (a, b, d, e, h, k, p, r, s, t, u, v, x, z, aa, bb & dd) the value for the Brungraber Tester exceeded the desired limit of 0.03 while in 18 cases (a, d, h, i, j, k, m, n, p, q, r, s, t, u, x, y, z & dd) the James Tester exceeded this limit. This indicates that in order to achieve the desired precision with either tester, it may be necessary under certain conditions to take more than one observation.

5.4. Calibration Procedure

In seeking the source of the systematic bias of the NBS-Brungraber Tester with respect to the James Tester, it would be desirable to have a method for calibrating both testers against a reliable standard. Such a method, using the gravitational attraction on dead-weights as a standard, has been developed and found to be adaptable to both testers. Both testers are currently being calibrated under a variety of conditions and the results of the efforts will be published in a forthcoming report. Preliminary results of the study, however, have revealed the following:

(1) Both testers tend to overestimate the static coefficient of friction. That is, the tangent of the angle that the articulated strut makes with the vertical is not, strictly speaking, the static coefficient of friction. It is, however, related to the static coefficient of friction by a reliable calibration curve or table.

(2) The calibration curve for either tester is affected by the adjustment of the tester and thus they must be carefully maintained and adjusted in accordance with the instructions.

(3) The calibration curve, for either tester, is a function of the inclination of the surface being tested. Thus, the James Tester should be carefully leveled before use, and the NBS-Brungraber Tester should be calibrated at the inclination at which it is to be employed.

Once the calibration of both testers has been completed, it is proposed that an extensive series of comparative tests on the two testers be conducted. It is expected that this series of tests would be conducted as a "round robin," making use of several NBS-Brungraber Testers and many of the James Testers that are currently in use. Thus the tests reported in this paper must be considered as preliminary.

6. CONCLUSIONS

Based on the preceding test results, and in observation of the different testers, the following conclusions can be drawn:

(1) The NBS-Brungraber Tester is a portable slip-resistance tester that can yield reliable indications of the slip-resistance of actual floors under true field conditions such as dry, wet or soapy.

(2) Under many circumstances the NBS-Brungraber Tester and the James Tester achieve comparable results. In the cases where they differ, it is impossible to establish for the present which tester is more nearly correct, since there is no well-defined standard for the measurement of coefficient of friction between shoes and walkway surfaces.

(3) On dry surfaces, the NBS-Brungraber Tester tends to yield values greater than those from the James Tester.

(4) In the cases where the James Tester yielded values significantly higher than the NBS-Brungraber Tester, the surface was either wet or soapy. This tends to confirm the contention that the James Tester can encourage the development of liquid-enhanced adhesion and thus yield unrealistically high values of the static coefficient of friction, which would cause the user to dangerously overestimate the slip-resistance of a surface under such conditions.

(5) The NBS-Brungraber Tester generally yields more conservative (lower) values of coefficient of friction on wet or soapy surfaces than

does the James Tester. Since this tester was designed to simulate the timing of load application that occurs in normal walking, it is believed that it more closely evaluates the slip-resistance of moist surfaces.

(6) Natural leather is a satisfactory material for evaluating the slip-resistance of floors, but slightly more consistent results could be achieved with a reconstituted leather.

(7) Washing with acetone could be used as a method for reconditioning the sensor facing, but this would entail a delay of up to 15 minutes while the acetone was evaporating, and thus sanding with 400-grit sandpaper is the superior alternative.

(8) Once the calibration procedure has been thoroughly developed and both the James and the NBS-Brungraber Testers have been calibrated, additional comparative testing using other shoe sole and heel materials and other floor surfaces should be conducted.

APPENDIX A

INSTRUCTIONS FOR THE OPERATION OF THE NBS-BRUNGRABER PORTABLE SLIP-RESISTANCE TESTER

Description of Components (Referring to Figs. A1 and A2)

A. Main frame
B. Travel bars
C. Carriage
D. Linear splined shaft, or pair of vertical round shafts
E. Articulated shaft
F. Recording shaft with magnet
G. Recorder clamp
H. Trigger
I. Sensor shoe
J. Weight
K. Handle
L. Retainer plate
M. Control springs
N. Attraction point for magnet with adjustment screw
O. Sensor facing clip (not shown)
P. Initial position stop (shown on Fig. A2)
Q. Trigger adjustment screw (shown on Fig. A2)
R. Adjustable trigger stop (not shown)
S. Indicator tube for recording shaft (not shown)
T. Adjustable collar

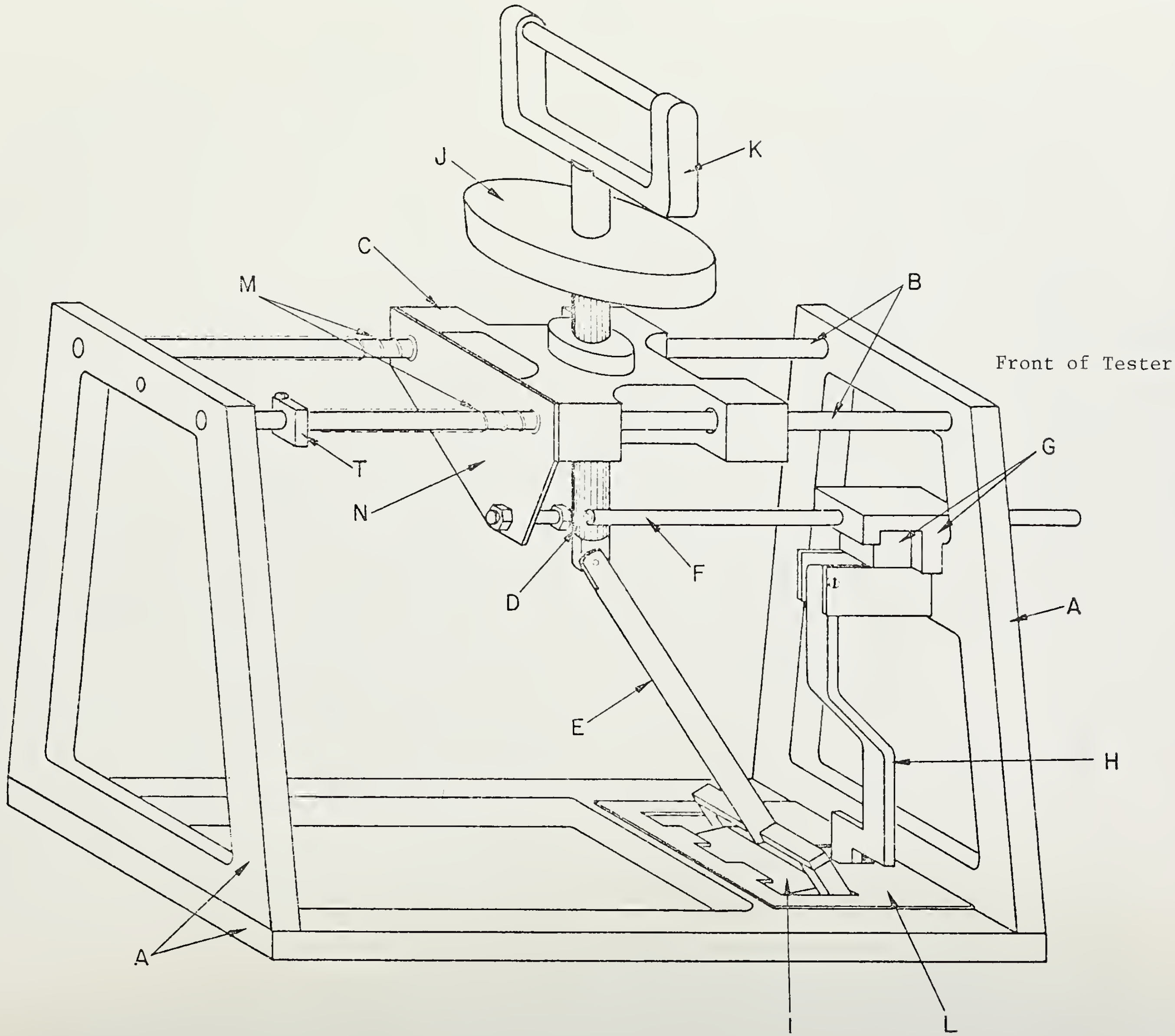


Fig. A1. Development Model of NBS-Brungraber Tester

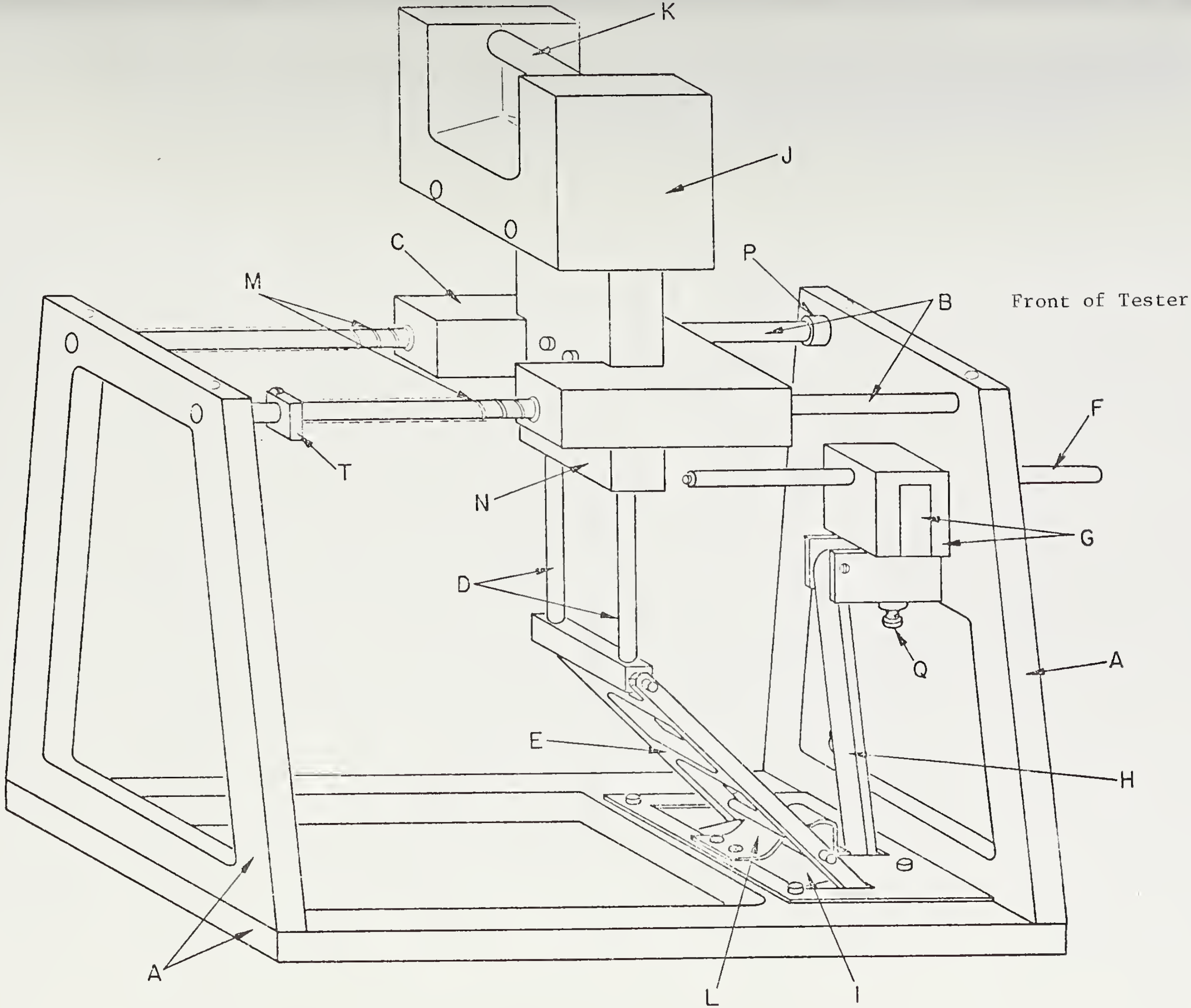


Fig. A2. Production Model of NBS-Brungraber Tester

Principle of Operation

The NBS-Brungraber Portable Slip Resistance Tester is designed to measure the static coefficient of friction between a representative sample of shoe sole material, such as leather, and a flooring surface, under true field conditions. It does this by applying a predetermined vertical force, (the weights, J) through a vertical splined or double shaft, D, and an articulated shaft, E, to the sensor shoe, I.

At the start of a test the carriage, C, is brought forward to a stop position such that the articulated shaft is not vertical but set at a slight angle towards the back of the tester (approximately equivalent to a tangent or coefficient of friction of 0.03). This establishes an unbalanced lateral force against the carriage. At the instant that the handle, K, is released and the vertical load is applied, the carriage begins to move back along the travel bars, B, inducing an increasing lateral load on the shoe as the angle between the articulated shaft and the vertical increases. The tangent of this angle at the moment that slip occurs is directly related to the static coefficient of friction. This angle is measured by the recording shaft, F, which is magnetized and drawn along by attachment to the attraction place, N, as the carriage moves backwards. When slip occurs the sensor shoe, I, hits the trigger, H, so that the recorder clamp, G, grips the recording shaft, F, retaining the shaft in its position at the time of slip. The measurement of slip-resistance is read opposite a notch in the indicator tube at the front of the recorder clamp, from a linear graduated scale imprinted along the length of the recorder shaft. This value can be directly translated to static coefficient of friction by use of the calibration chart or table supplied with the tester.

The motion of the carriage is controlled by the springs, M. The retaining plate, L, and a similar plate below the main frame help to keep the shoe in position while the tester is being lifted and moved to a new test location.

Preparation for a Test

In order to obtain consistent results with any slip-resistance tester, it is essential that the sensor facing be maintained in a consistent condition. This is done on the NBS-Brungraber Tester by unclipping the sensor facing clip, O, from the shoe, I, so that the facing surface can be stroked 4 times in each of 2 perpendicular directions against a sheet of 400-grit sandpaper held against a flat, uniform surface. This must be done at least before each series of tests for a given floor surface and a given test condition. (For evaluating bathing surfaces a sensor made of an RTV (Room Temperature Vulcanizing) silicone material is used, which need not be conditioned by sanding.) In the event that lack of repeatability demonstrates that the facing is picking up wax, dirt or other extraneous material from the surface being evaluated, it may be necessary to resurface or recondition the shoe facing more frequently.

The floor surface should be in a condition representative of the service conditions to be evaluated; waxed or bare, buffed or unbuffed, wet or dry, dirty or clean etc. An area large enough to permit at least three independent tests must be selected such that the service conditions are uniform over the entire area. The NBS-Brungraber Tester is a sensitive instrument and inconsistency or nonrepeatability of results demonstrates that either the floor surface being tested is not uniform or else that the sensor facing is picking up extraneous material.

If a wet floor surface is to be tested, the sensor facing should be soaked in water before the test to simulate the likely condition of the shoe sole or heel on a wet and rainy day.

Step-by-Step Operation of the
NBS-Brungraber Slip-Resistance Tester

1. Carefully remove the tester from its case, inspecting for any loose or damaged parts.

2. Using a clean cloth or paper napkin, thoroughly wipe all parts of the main, horizontal travel bars, (B) that come in contact with the linear ball bushings in the carriage (C).

3. Select a sensor clip, (O) having a suitable facing material, and slip it to the bottom of the sensor shoe, (I) making certain that the vertical extension on the clip extends up through the hole in the base plate (the bottom portion of the main frame A) and lies <u>behind</u> the trigger (H). Also be certain that the clip is pushed back with respect to the shoe as far as it will go, so that the vertical extension on the clip is thoroughly engaged in the single notch at the front of the shoe.

4. Remove the indicator rod (F) from the case and wipe it thoroughly with a clean cloth or paper napkin.

5. Insert the magnet end of the indicator rod through the indicator tube (S) at the front of the tester, pushing the rod back until the magnet engages the head of the adjustable carbon steel bolt (N) attached to the carriage. While inserting the rod, be certain that the trigger-clutch assembly (G) is thoroughly released by pushing the sensor shoe as far towards the rear of the tester as it will go. If the rod fails to slide in easily, it may be necessary to back off the adjustment screw (Q) in the upper end of the trigger. This is done by first releasing the knurled lock nut on it.

6. The adjustment of the trigger mechanism is made by first putting the tester on a level surface, with the sensor shoe to the rear of its

possible travel and with the carriage fully forward, with the initial stop (P) removed. Then adjust the trigger so that the 0.05 in (1.27 mm) thick spacer, supplied with the tester, can be easily placed between the trigger and the vertical extension on the front of the sensor clip. Set the trigger stop (P) so that there is also a 0.05 in (1.27 mm) gap between the stop and the front of the trigger, with the trigger again at the front of its travel. At no time during these adjustments should the trigger be pushed hard enough to bend it. The 0.05 in (1.27 mm) gap between the trigger and the stop permits some elastic bending of the trigger during operation of the tester, but the trigger should be free of bending stress while being adjusted.

7. With the carriage fully forward and the magnet of the indicator rod engaged with the bolt in the carriage, the zero reading should be checked. If the zero line on the indicator rod does not lie opposite the notches in the indicator tube, bring them into alignment by releasing the wing nut on the bolt in the carriage and adjusting it as needed. Before attempting to adjust the zero position of the indicator rod, first check the indicator tube to be sure it is tightly secured in the front of the tester and is so positioned that the indicator rod may be easily read from the top of the tester.

8. Check the free movement of the indicator rod by holding the sensor shoe in its rearward position and moving the carriage, by hand, throughout its travel. The indicator rod must travel freely, without breaking the magnetic attachment to the bolt in the carriage. If the rod does not move freely, the rod should be checked for straightness. If the rod has been bent, it may be possible to carefully straighten it; if not, it must be replaced. During this operation, the sensor shoe can be held in its rearward position either by hand or by temporarily adjusting the trigger stop such that all movement of the trigger is prevented.

9. With the tester on a level surface and the sensor shoe again held in its rearward position, adjust the spring-control collar (T) so that

the carriage will move freely throughout its entire travel, using the initial-position stop to initiate the travel. That is, the collar should be adjusted such that the carriage, while dragging the indicator rod, will just move to the end of its travel (the weight fully descended), without causing an excessive bump at the end of the travel.

10. With the tester fully adjusted, the proper sensor in place, and the initial stop (the short piece of flexible plastic tubing) installed at the front of one of the main travel bars, conduct a test by picking up the tester by the handle, placing it on the area of the floor to be evaluated and releasing the handle. Read the value of the resulting NBS-Brungraber number from the indicator rod at the index formed by the pair of notches in the indicator tube. Then convert the NBS-Brungraber number to an equivalent value of static coefficient of friction by means of the calibration chart or curve that are supplied with the tester. When picking up the tester, care should be taken to see that the clutch is released permitting free movement of the indicator rod, before the indicator rod is forced forward to its initial position. This can most easily be done by inducing a slightly rearward force on the handle during the initial part of the picking-up operation. This assures that the sensor shoe is lifted free of the floor permitting it to return to its initial position, releasing the trigger and clutch, before the indicator rod is pushed by the carriage back to the initial position.

11. By repeating the procedure of step 10, additional readings can be taken at the same or newly selected spots on the walkway surface. When taking repeat tests at the same identical spot, hold the tester in place with one hand while operating it with the other. In this case, exercise special care to be sure to apply a rearward bias to the handle when first lifting it, to assure that the indicator rod is free to be returned to its starting position.

12. It should be noted that, with the initial-position stop in place, readings of less than 0.5, which corresponds to a static coefficient of friction of about 0.03, cannot be taken. However, such values of coefficient of friction are quite low and would represent an extremely hazardous condition for most walkway surfaces. In fact the operator of the tester would have to exercise great care to prevent self-injury. In the event the presence of water or other contaminant on the surface makes it so slippery that the tester registers a value equal to the initial setting of the tester indicating that the indicator rod did not travel at all, a repeat test should be performed with the initial-stop removed. In this case, the tester is not self-starting, and it will be necessary to impart a slight rearward push to the handle as soon as the sensor comes in contact with the floor. It is important that there be no delay between the contact of the sensor with the floor and the start of the carriage movement, since it is under those circumstances (the presence of water or other liquid contaminants) that a time delay will permit the squeezing out of the contaminant which may promote adhesion of the sensor to the floor, resulting in an unrealistically high indication of the slip-resistance of the walkway surface.

When evaluating extremely slippery surfaces, such as bathtubs or shower bases in the presence of soapy water, certain modifications must be made to the previous instructions for the operation of the NBS-Brungraber Tester, which were for dry, level floors.

To promote free and complete drainage, most bathtub and shower base surfaces have a built-in slope, towards the drain, of about 1-1/2° - 2°. By taking advantage of this slope and operating the NBS-Brungraber Tester "uphill," it can be so adjusted that it is self-starting without the use of the initial-position stop. This permits the measurement of low values of coefficient of friction, less than 0.03, while still retaining the desirable self-starting feature which reduces operator error. Thus, wherever possible bathtub and shower surfaces should be tested "uphill" at a 1° - 2° slope and the tester should be adjusted and calibrated for this mode of operation. The term "uphill" is meant to describe the condition of having the front of the tester higher than the rear.

The first eight steps of the instructions for the use of the tester on dry, level floors apply to the presently discussed application as well. For the ninth instruction, the adjustment of the spring-control collar, the adjustment should be carried out with the tester inclined "uphill" at the approximate angle it is to be used and with the initial-position stop removed. In the tenth and eleventh instructions, the actual operation of the tester, the initial-position stop must be removed and the test must be conducted in the "uphill" direction. If it is too difficult to incline the surface and it must be tested in the level position, satisfactory results can be obtained by carefully following the instructions of step 12. However, the tester must then be adjusted and calibrated for use on a level surface. When evaluating such surfaces as bathtubs or shower bases, particular care should be used to hold the tester in place with one hand while operating it with the other, since movement of the tester during the measurement operation will result in a false reading.

Calibration of the Tester

The scale on the NBS-Brungraber Tester is graduated in tenths of an inch. The value read from this scale can be used directly in comparing the relative slip-resistance of materials, or the corresponding value of static coefficient of friction can be determined from a calibration chart or table, supplied with the tester.

Calibration of the NBS-Brungraber Tester is effected by comparison with standard weights or springs which are applied in such a manner as to provide a precisely controlled, simulated friction force. This is done by installing a low-friction pulley at the rear end of the tester, replacing the sensor shoe with a low-friction linear ball bearing (a unit supplied by Turnomat, Inc. of Rochester, New York has been found to be satisfactory) and placing the tester on a carefully leveled sheet of plate glass. A string and bridle arrangement attached to the shoe, passing over the pulley and aligned horizontally, permits the simulation of a well-defined friction force by attaching standard weights to the string. The weight on the string, plus the extremely small drag force of the linear ball bearings, divided by the total of the weights on the articulated strut, including the weight of the strut, shoe, sensor, etc., is the simulated coefficient of friction. This is compared with readings from the tester for a series of different loads on the string. The results are presented in the form of a calibration chart or table.

The two existing models of the NBS-Brungraber Tester have been calibrated repeatedly, in the horizontal position as well as tilted laterally as much as 4°. The results to date indicate that the calibration is essentially the same for both testers and is not affected by lateral tilts of up to 4°.

The testers have also been calibrated after being modified or adjusted to permit the evaluation of sloping surfaces in the "uphill" mode. For testing such surfaces the collars for the control springs must be adjusted to prevent excessive speed of travel of the tester carriage. For surfaces inclined up to as much as 4°, if the tester is adjusted as described to permit full travel of the carriage without an excessive jolt at the end of travel, satisfactory calibrations are obtained.

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The paper describes the available devices for testing the slip-resistance developed between walkway surfaces and shoe sole or heel materials. The limitations of available testers are detailed, and the need for a more reliable tester that can be used on actual floors under true field conditions, such as in the presence of water, is shown. The design and development of the new NBS-Brungraber Slip-Resistance Tester is described, including a discussion of the test programs that were employed to evaluate it.

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