FOOTWEAR SAFETY & TRACTION IN THE WORKPLACE

By WILLIAM ENGLISH

[Above]: Keith Vidal [left] and David Underwood take wet readings with the VIT as part of the 1998 OSHA slip-resistance research project.

Slip/fall accidents are the dominant controllable loss type in American workplaces. Fall-related injuries are more widespread than many analytical reports show, because accident statistic programs often under-report fall-related injuries for various reasons (English and Marletta 112). But the prevention of workplace falls is today's remaining safety engineering frontier in labor-intensive industries.

Due to the confusing output among traditional slipmeter types, safety engineers have not been very trusting of tribometric technology; as a result, traction measurement devices have not been widely used in the quest for safer workplaces. Controversy concerning traction testing philosophy continues despite recent advances in measurement capability. This article addresses the leading questions in the debate: 1) What are investigators trying to measure in an effort to rank relative footwear traction? 2) What testing standards are applicable?

Over the latter half of the 20th century, more than 100 distinct types of slipmeters were developed and described in the scientific literature. Only during the last decade, however, has the reason for their general invalidity been understood. Specifically, cognizance of the *sticktion* phenomenon in the scientific literature concerning pedestrian traction has enabled the design of slipmeters that have no *residence time* and can, therefore, avoid this disabling defect.

BASIC TRIBOMETRY TERMINOLOGY

What is residence time? It is the period of time that a slipmeter's friction pad rests on the test surface before horizontal motion is initiated. If slip resistance of a dry surface is being measured, the longer the testfoot rests on the surface, the higher the slip index will be. This arises from the tendency of the friction pad to conform to the test surface under the normal load applied by the slipmeter. The resulting conformance to the topography of the test surface is called *adhesion.*

If a wet surface is being metered, the result of the normal load on the testfoot is to squeegee water out of the interface in residence times as small as a fraction of a second, thereby resulting in misleading readings. The sticktion problem is more pronounced when a lubricating film with a very low viscosity (e.g., water) is on the interface. Residence time is less critical if the film is relatively thick and strong (e.g., engine oil); with water, it is critical.

Most slips and falls result from wet or otherwise lubricated surfaces (Armstrong and Lansing 3-10). When clean and dry, ordinary walking surfaces are not slippery under rubber-like shoe bottoms. Therefore, slipmeters that cannot take valid readings on wet surfaces are relatively uninteresting to the accident prevention practitioner.

HOW FAST MUST A SLIPMETER'S APPLICATION BE?

As the widely-used ambulation traces by Grönqvist, et al show (Figure 1, pg. 24), in normal walking, the disastrous heel-slide type of incident occurs within about 1/20 second after initial heel contact. It is clear, therefore, that any slipmeter which cannot measure surface traction in less time than that is not fast enough to be useful for metering wet surfaces in order to evaluate them for pedestrian safety.

The problem is more complicated than the duration of residence time, however. In normal walking, the shoe contacts the floor heel-first, with the foot at perhaps a 30-degree angle to the walking surface. It then rotates rapidly into a flat position on the walkway, thereby manipulating the hydrodynamic squeezefilm in a formation that lubrication theorists call "the wedge."

It is this dynamic maneuver that provides the opportunity for slipping if the surface does not have sufficient texture to forestall slipping. What makes a surface slip-resistant is the sharpness and height of surface asperities that extend upward through the squeezefilm so as to engage the shoe bottom in a manner similar to sandpaper.

To the extent that these peaks can

FIGURE 1

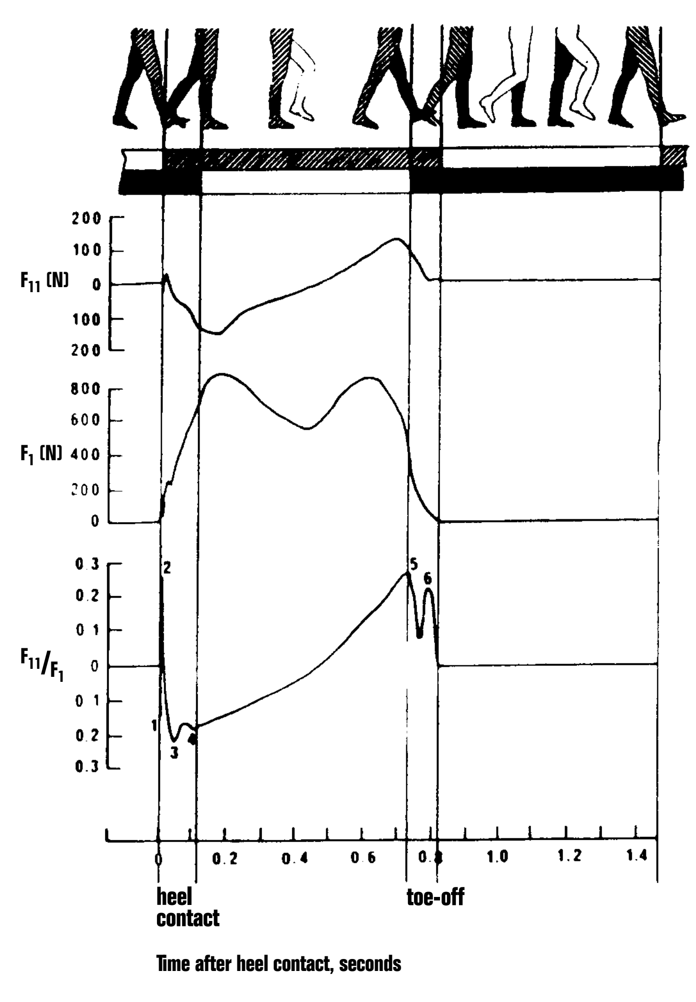


FIGURE 2

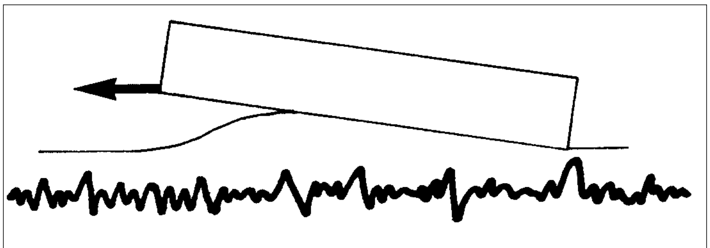


Figure 1 (left): Grönqvist, et al, among others, have plotted ambulation dynamics using a three-axis forceplate. Peak 3 has been identified at the critical point where slipping is most likely to occur.

Figure 2 (below): The dangerous heel slide that produces the most common disabling fall is controlled by installing a walking surface that has asperities sufficiently aggressive to penetrate the hydrodynamic squeeze-film and physically engage the shoe bottom (English 4).

extend through the film and engage the edge of the heel, the floor is slip-resistant under test conditions. To the extent that the horizontal force component is applied before sticktion can be achieved, the heel will slide. It is this type of incident that produces the most serious slip/fall injuries. Thus, in order to enable valid inferences concerning surface traction, a slipmeter's dynamics must bear some analog to those of ambulation (English 347-352).

HOW IS THIS NOTION APPLIED TO SLIPMETER EVALUATION?

Based on this philosophical understanding, it is possible to eliminate all dragsled instruments and the James Machine for use on wet surfaces because of disabling sticktion. This is confirmed by a study of current ASTM slip-resistance testing standards. ASTM F13 on Safety and Footwear Traction has several standards for measuring pedestrian slip resistance.

F489-96
Test Method for Static Coefficient of Friction of Shoe Sole and Heel Materials as Measured by the James Machine

This standard purports to cover the evaluation of various shoe bottom materials on a variety of test surfaces in a clean, dry condition. It does not permit wet testing and cannot be used in the field for actual walking surface traction measurement. Much shoe traction testing being performed with the James Machine is still being conducted under wet conditions—in violation of this standard. Results, therefore, are clearly inaccurate, as is recognized among active members of F13.

Although several examples of the James Machine exist (at least four versions), it is currently available only in a computerized rendering from the latest entity willing to try to make this device profitably (www.michem.com). F489-96 is applicable only to the original model with the manually propelled table (Figure 3). No standards exist for the electrically propelled model or the Jablonski enhancement, not to mention the current digitized version.

F609-96
Test Method for Static Slip Resistance of Footwear, Sole Heel or Related Materials by Horizontal Pull Slipmeter (HPS)

This covers a specific type of dragsled meter; it is the only meter with an F13 standard addressing its use. However, its failure as a metric for wet traction applies equally to all dragsleds, including those for which no ASTM standard exists. F609-96 gives no procedure for wet testing because the HPS is incapable of producing valid results under wet conditions.

The HPS (Figure 4) has been produced by several manufacturers, but is no longer commercially available. Other dragsleds on the market do not comply with F609-96.

F1677-96
Test Method for Using Portable Inclinable Articulated Strut Tester (PIAST)

This standard applies to the *Brungraber, Mk II* slipmeter. It is applicable to both wet and dry testing. Although experimentation continues on the design of this device's testfoot, it avoids sticktion by applying the vertical and horizontal dynamics to its testfoot simultaneously. PIAST is currently in production and is commercially available.

F1678-96
Test Method for Using a Portable Articulated Strut Tester (PAST)

The *Brungraber, Mk I* (formerly known as the NBS Standard Static Coefficient of Friction Tester) is the subject of this standard. No procedure is given for wet testing. In fact, the Mark II was invented to circumvent the sticktion problem known to plague the Mark I. The PAST is still commercially available.

F1679-96
Test Method for Using the Variable Incidence Tribometer (VIT)

This standard for the *English XL* slipmeter is the newest F13 tribometry standard. The VIT was designed primarily for wet testing, and many of its proponents express confidence in its validity on contaminated surfaces because of its analog of ambulation dynamics.

DYNAMIC OR STATIC COEFFICIENT OF FRICTION—WHICH IS IMPORTANT?

This argument had subsided, with the Americans and Europeans agreeing to disagree. However, following invention of the SATRA Machine in England, which, despite its complexity, was incapable of beating sticktion for wet testing, proponents in the European Union began to theorize that static friction does not exist; consequently, they became interested in measuring dynamic coefficient of friction (DCOF). The SATRA Machine has been dubbed a DCOF tester since its introduction as a commercial shoe tester in England in the 1970s.

What is the difference between static coefficient of friction (SCOF) and DCOF, and what does either have to do with pedestrian slip resistance?

SCOF has been defined as the force required to initiate horizontal motion of the testfoot on the test surface; in classical physics, it is expressed as the ratio of the horizontal force to the normal force (vertical load) required to initiate motion in dragsleds. For articulated strut testers, it has been expressed as the tangent of the angle from the vertical at which the horizontal force overrides the adhesion and the testfoot begins to slide. By either expression, close contact of the testfoot with the test surface is assumed; that means sticktion or adhesion is inherent in the process if there is residence time.

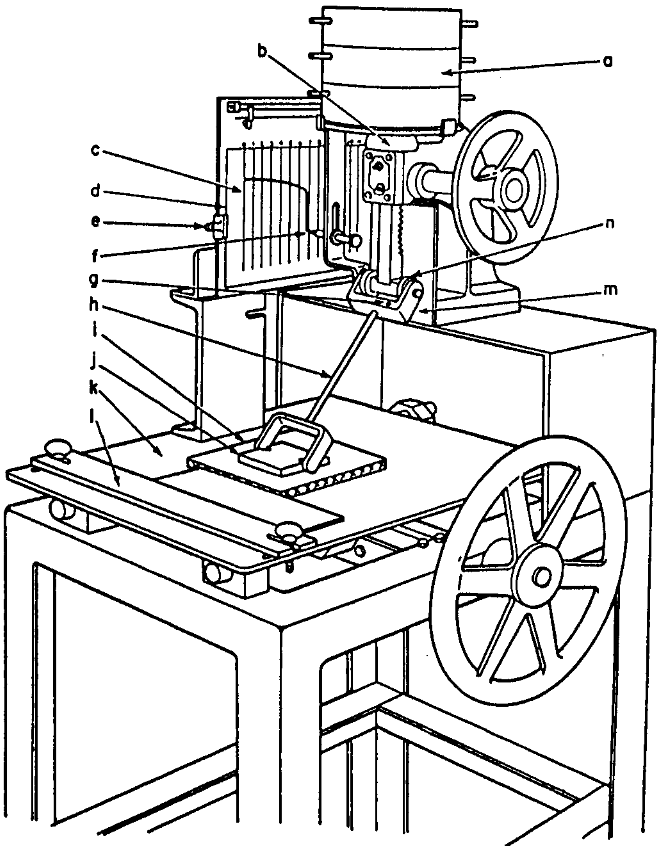
DCOF has been defined by Europeans and most Americans as the force required to keep a sliding object in constant motion. This is not relevant to pedestrian safety because, as shown in Perkins' strobe flash photograph (Figure 5), in an accidental heel slide, once slipping is initiated, the shoe accelerates freely across the surface until the victim's posterior hits the pavement. There is nothing constant about that motion, so the European definition is not relevant to pedestrian slip resistance.

Therefore, investigators of pedestrian safety are not concerned with either SCOF or DCOF. The study of slip resistance must focus on the tendency of surface asperities to penetrate the squeezefilm and prevent initiation of a heel slide.

Careful reading of the two ASTM F13 standards for slipmeters recognized for wet surface testing will reveal that SCOF, DCOF or COF are not mentioned. Writers of these standards wanted to bypass the static/dynamic argument and focus on measuring what occurs under the heel in walking. This is slip resistance, and it is measured as a *slip index*.

Manufacturers of dragsled devices have attempted to point out that traditional

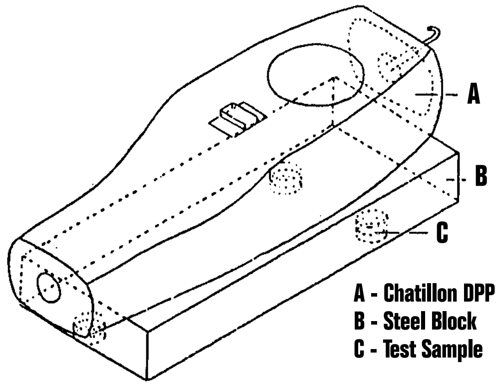
FIGURE 3 James Machine



a - Weights
b - Cushion
c - Chart
d - Chart Board
e - Spring Clip
f - Recording Pencil
g - Set Screw
h -Strut
i - Specimen
j - Shoe
k - Test Table
l - Retaining Bar
m - Back Plate
n - Ball Bearing Rollers

The James Machine continues to be the subject of the oldest slip-resistance testing standard (ASTM F489-96).

FIGURE 4 Horizontal Pull Slipmeter



A - Chatillon DPP 5 Gage
B - Steel Block
C - Test Sample

Note: Total weight of slipmeter less power unit is 2700 ± 34 g. Speed of power unit is 3.5 ± 0.5 in/min.

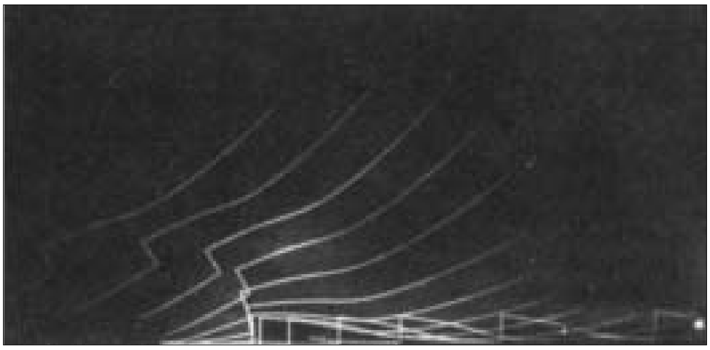
The HPS had minimal specifications (ASTM F609).

Slip/fall accident prevention practitioners primarily need to investigate lubricated surfaces.

Robert Brungraber [right] demonstrates the PIAST at the F13 Round Robin for precision and bias studies at ASTM in 1997.

FIGURE 5 Perkins' Strobe Photography

In the most significant article ever written about slipmeters, multiple-image strobe photography shows acceleration in the skid appears to have reached a velocity of about 66 inches/second within 1/3 second (Perkins).



pedestrian safety standards have made reference to SCOF; thus, they contend, since their devices measure SCOF, they are preferable to PIAST and VIT. Actually, the latter are far superior to SCOF testers because, in addition to SCOF, they can measure slip resistance on lubricated surfaces.

Both PIAST and VIT measure SCOF, if one is metering dry surfaces. That is, they apply the testfoot in such a manner as to measure the tangent of the angle from the vertical at which slip just begins to occur. If no contaminant is present on the surface, that is SCOF by NBS definition. These two devices avoid adhesion on dry surfaces as well, so their results are more reproducible even for dry testing.

On the other hand, when using PIAST and VIT for wet testing, testing stops when the angle of strut inclination is reached where slipping occurs—when the slip point is determined. Therefore, the indication cannot be DCOF by any definition that has been widely presented in tribometry literature. In another sense, however, it does not matter. As long as the slipmeter is mimicking the action of the foot in walking, it is manipulating the hydrodynamic squeezefilm in the same way and is measuring available traction with a standardized methodology recognized by ASTM F13.

WEBSITES OF INTEREST

www.asse.org
www.astm.org
www.osha.gov
www.ul.com
www.access-board.gov/history.htm
www.turnbow.com/safety.htm
www.englishxl.com/techbab.html
www.slipmeters.com
www.slipandfall.com

CONCLUSION

DCOF or SCOF are not relevant indicators in the investigation of footwear traction. Slip resistance is the relevant parameter; it is commonly expressed as the slip index in terms of slipmeter output. Slipmeters that are valid under real-world test conditions should be used, or misleading results will be recorded. Misleading results do not effectively contribute to making the world safer for walking.

Since ordinary clean, dry surfaces are not slippery, slip/fall accident prevention practitioners primarily need to investigate lubricated surfaces; that limits them to a choice of two standard slipmeters that F13 recognizes for wet testing: PIAST (F1677) and VIT (F1679). ■

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