Slip Resistance

Field measurements using two modern slipmeters

By Brian C. Grieser, Timothy P. Rhoades and Raina J. Shah

SH&E PROFESSIONALS HAVE LONG recognized slips and falls as a major cause of injury and, therefore, are keenly interested in the assessment of slip resistance for walking surfaces. Many devices have been developed over the years to help SH&E professionals perform quantitative assessments of slip resistance, but most have been hampered by an inability to produce valid measurements under wet conditions. In particular, most testers provide artificially high readings on wet floor surfaces due to adhesive forces that develop when there is a delay between the test foot's contact with the surface and the application of horizontal force.

Two modern devices designed to overcome the adhesion effect are the Brungraber Mark II and the English XL. With these devices, one can more-accurately assess walkway slip resistance under wet conditions. The objectives of this study are to provide SH&E professionals with practical information regarding the use of these devices and to report slip-resistance measurement values for various floor surface materials in "as purchased condition" under wet and dry conditions using both devices.

Experimental Design & Test Materials

This experiment, conducted under laboratory conditions, employed a complete factorial design in which the independent variables were testing device, floor surface material, floor surface condition and test device operator. The dependent variable was slip resistance.

Testing Devices

The two testing devices employed were the Brungraber Mark II[1] portable inclineable articulated strut slip tester (Photo 1) and the English XL[2] variable incidence tribometer (Photo 2).

The Brungraber Mark II utilizes a three-inch-square test foot attached to an articulated strut that in turn connects to an inclined aluminum support. The support can range in angle from vertical to an angle slightly more than 45 degrees from vertical. Attached to the top of the inclined support is a 10-lb. cast-iron weight that provides the force with which the test foot strikes the test surface. The device may be either trigger or manually actuated.

The English XL utilizes a circular test foot with a diameter of 1.25 inches. The test foot is connected to an actuating cylinder that is, in turn, attached to a mast assembly. The mast assembly is a rigid aluminum frame that can vary in angle from vertical to 45 degrees from vertical. The tester is powered by a compressed gas cylinder and is activated by pressing a palm button.

Test Foot Material & Configurations

Test-grade Neolite® rubber[3] was used as the test foot material for both devices. The material was chosen for its many desirable characteristics such as consistency, low water absorbency, wear resistance and acceptance as a test foot material (e.g., ASTM 5859-1996). Initial data collection revealed a potential hydroplaning phenomenon with the standard smooth Neolite® test foot on the Brungraber device; therefore, an alternative test foot was used at the manufacturer's recommendation. (Although not reported in this article, statistically significant lower

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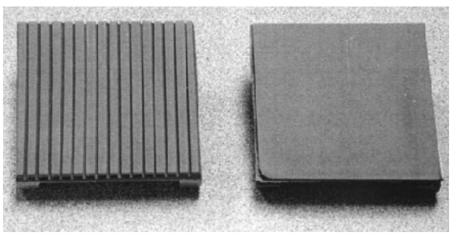
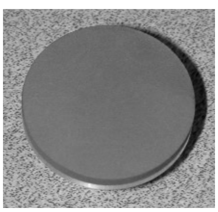




Clockwise from top: Photo 1: Brungraber Mark II.

Photo 2: English XL.

Photo 3: Brungraber test feet (3" x 3" grooved and ungrooved).

Photo 4: English test foot (1.25" diameter.

readers were also found with the ungrooved test foot under dry conditions.) The alternative foot was ¼-inch thick and had 15 equidistant grooves, approximately ⅛-inch deep, that ran parallel to the direction of travel of the foot (Photo 3). The grooved test foot was used for all Brungraber Mark II data reported in this study. The single foot used on the English XL (Photo 4) was ⅛-inch thick, circular and not grooved (as no hydroplaning effect was experienced with this configuration during testing).

Floor Surface Materials

Six floor surfaces were selected for testing (Table 1). The surfaces were selected in an attempt to test a variety of common floor materials.

Additional Instrumentation

The following additional test instrumentation was used: 1) traceable digital hygrometer (Model No. 4184[4]); and 2) digital protractor (Model DGP3607[4]; 0.1º resolution).

Test Procedure

Tests were conducted according to ASTM F1677-96 (Mark II) and ASTM F1679-96 (English XL) standards and the manufacturers' recommendations.

Preparation

Prior to testing, test surfaces were cleaned with a solution of one part dishwasher detergent to 14 parts water. Surfaces were then rinsed with distilled water and wiped dry with clean paper towels to remove any soapy residue and water. An operational check was then performed on each testing device.

The slope of the test floor surfaces was also measured prior to testing to confirm that it was level (≤0.1 degree). Temperature and relative humidity were measured during all testing as well and were found to be between 73ºF and 77ºF and 41 percent and 52 percent, respectively. For all tests, two of the authors operated the slip testers. Before testing and after each slip during the dry testing, the test feet were sanded with 180-grit silicon carbide sandpaper in approximately two-inch diameter circular motions five times each in both the clockwise and counterclockwise directions. This was performed a minimum of six feet from the test area to prevent accumulation of sanding dust on the test surface. After sanding, the test feet were brushed clean to remove sanding dust residue.

Dry Testing

During dry testing, four repetitions were performed on each floor surface. These repetitions were each performed in a different compass direction (north, east, south and west) relative to the floor surface. All test runs were randomized by floor sample, test direction, slipmeter and operator. Each repetition consisted of a series of "strokes" of the slipmeters, starting at a slip-resistance value below that of the surface being tested. The mast angle (from vertical) was then increased in slip-resistance increments of 0.01 until a slip occurred. The recorded slip-resistance value was that at which a complete slip first occurred. Test feet were sanded after each slip.

Under certain conditions, particularly with Neolite® rubber test feet, the Brungraber test foot can have a tendency to bounce off the floor surface, resulting in artificially low readings. In particular, this can occur when the trigger is used to release the test foot onto the test surface. To avoid this problem, the instrument was manually actuated throughout the testing.

Wet Testing

All wet testing was performed in a similar manner to the dry testing, with a few modifications. During all wet testing, distilled water was added as needed so that an unbroken water film was present across the entire test foot contact area. Also, test feet were not sanded after each slip during wet testing, only before the start of the testing. During wet testing performed with the Mark II, only the grooved foot was used because of the aforementioned hydroplaning phenomenon. For wet testing performed with the English XL, the test foot and nylon nut were both rotated one-quarter turn after each slip as recommended by the manufacturer. Once

Table 1

Tested Floor Surface Materials

Floor Material Type	Company	Model No./Description
Smooth ceramic tile (A)	American Olean	GE12121P[5]
Smooth ceramic tile (B)	Classic Tile	825805000[5]
Terrazzo	Central Tile and Terrazzo	60% Botticino #1 & #2, 40% Texas Yellow #1 & #2, White Cement[6]
Quarry tile	VersaTile	EQ848[5]
Vinyl composite tile (VCT)	Armstrong	Imperial Texture 51911031[5]
Vinyl tile (linoleum)	Armstrong	Caspian 64804[5]

[5]*Available from Lowe's Home Improvement Warehouse (nationwide chain store)*
[6]*Available from Central Tile and Terrazzo Co., 5180 S 9th St, Kalamazoo, MI 49009*

again, the recorded slip-resistance value was that at which a complete slip first occurred.

Results

As one might expect, an ANOVA (analysis of variance) of the combined data for both devices revealed that slip-resistance values were significantly higher (all reported statistics significant to p≤0.05 level) in the dry testing condition than in the wet testing condition (0.925 versus 0.485, respectively). Table 2 shows the average values for the two devices for both wet and dry testing.

Figure 1 displays how the test results for the wet and dry conditions compare for the two devices and six floor materials. The effect of surface condition was so great that for subsequent analyses, wet and dry data were analyzed separately. For all testing, there were no significant effects of operator, order or direction. The effect of surface condition was substantially different for the various floor surface materials. For example, smooth ceramic tiles lost 75.2 percent to 77.1 percent of their slip resistance when wet; quarry tile lost only 10.8 percent of its slip resistance.

Dry Testing

For dry testing, the average slip resistance was 0.91 as measured by the Brungraber Mark II and 0.94 for the English XL. This 0.03 difference was a statistically significant but insubstantial difference (F=6.30, p≤0.0167). While the English XL provided higher slip-resistance values than the Brungraber Mark II for most of the individual surface materials, the difference in the results of the two devices was never greater than 0.05 for any one surface (Figure 2).

Wet Testing

For wet testing, no significant difference was found in the readings from the two devices (0.49 and 0.48 for the Mark II and XL, respectively). Again, there were significant differences in slip resistance among the floor materials tested (Table 2) (F=308.9, p≤0.0001). Compared to the Brungraber Mark II, the English XL yielded a higher slip-resistance reading for the terrazzo and a lower reading for the remaining five materials, which resulted in a significant interaction between floor surface material and testing device (F=11.91, p≤0.0001). The explanation for this interaction is unclear. Figure 3 shows the average slip-resistance values from the wet testing.

Ranking of Surfaces by Slip Resistance

With respect to the ranking of various floor materials by slip resistance, the two machines appeared to be similar (Table 3). Under dry conditions, readings from both devices showed linoleum to be the most-slip-resistant surface, followed by smooth ceramic tiles, quarry tile, terrazzo and VCT. Under wet conditions, both devices found the quarry tile to be the most-slip-resistant and the smooth ceramic tiles to be the least-slip-resistant. A small discrepancy was noted between the two devices in that the XL measured wet terrazzo to be more slip resistant than wet

Why Is Neolite® Used?

As described in this article, test-grade Neolite® rubber was used as the test foot material. Neolite® is a material with a record of providing reliable and repeatable slip test data in a variety of conditions. The test-grade used for slip-resistance testing is manufactured so that its physical properties (e.g., density and hardness) are consistent across test specimens. Unlike materials such as leather, Neolite® has low moisture absorbency and sensitivity, and its physical properties are not permanently changed when exposed to water. Also, its slip-resistance properties change very little, if at all, as it ages and wears. Neolite's traction properties are considered to be in the medium range in comparison to other commonly used heel and sole materials (Di Pilla and Vidal xx); it should be noted that a floor surface which achieves a 0.50 value with Neolite® will not necessarily achieve 0.50 with all non-Neolite shoe bottom materials. These favorable properties have helped make it a material of choice for much of ASTM's recent slipmeter test activities. Neolite® is also the standard factory-supplied test foot material provided with the English XL.

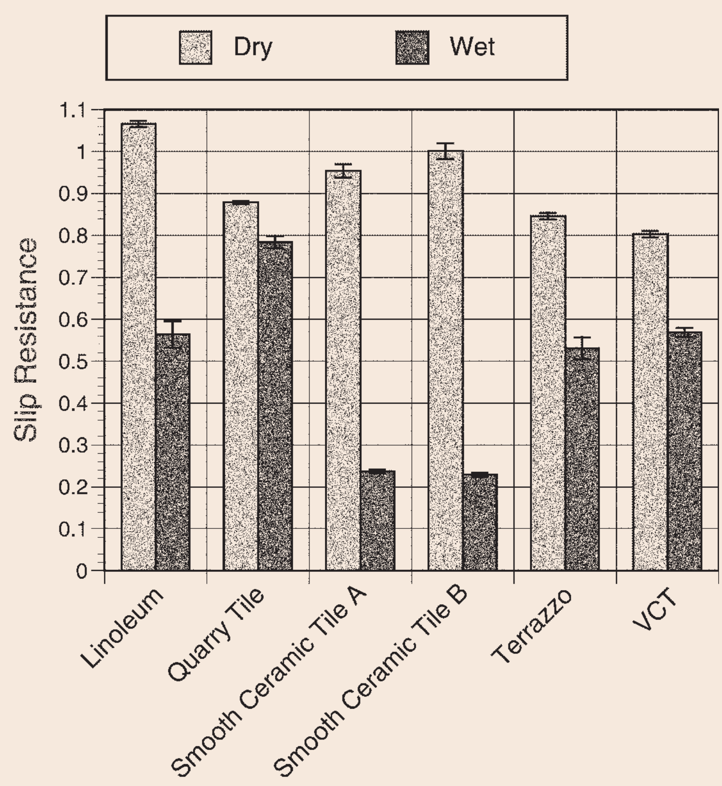
Table 2

Average Slip-Resistance Values for Wet & Dry Testing

Test Device	Dry	Wet
Brungraber Mark II (grooved foot)	0.91	0.49
English XL	0.94	0.48
Overall (both devices)	0.925	0.485

Figure 1

Average Slip-Resistance Values for Dry vs. Wet Testing

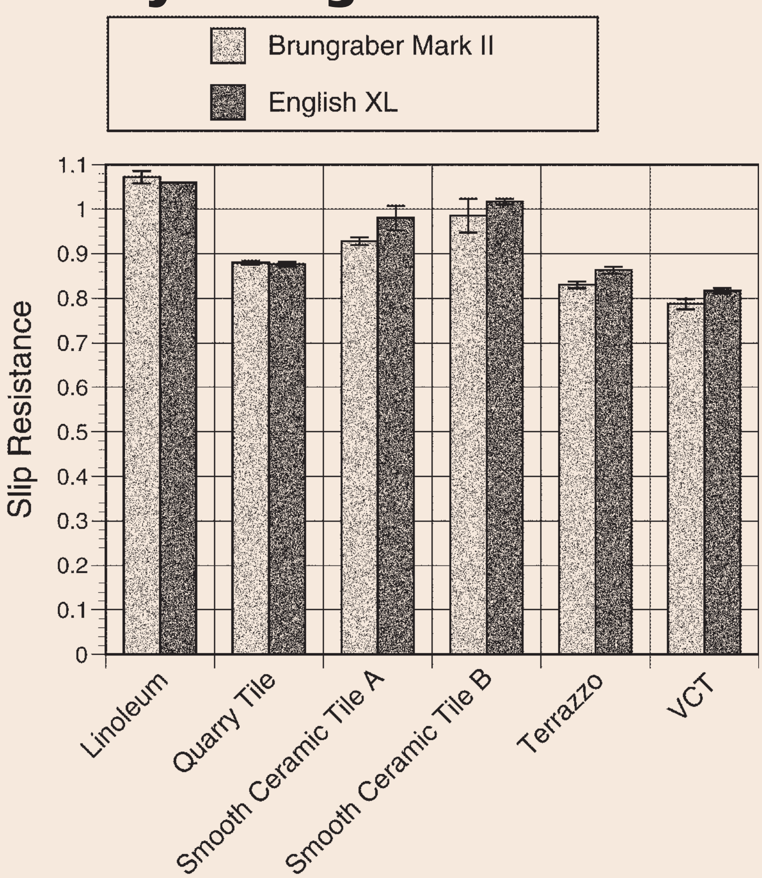


How Much Slip Resistance Is Needed?

Although we often talk about the slip resistance of a floor, slip resistance is actually related to three major factors: 1) surface conditions (i.e., floor material and finish); 2) absence or presence of contaminants (e.g., dirt and liquids); and 3) footwear characteristics (i.e., tread material and pattern). To evaluate the slip resistance of a floor under all variations of contaminants and footwear is impractical. ANSI A1264.2, Standard for the Provision of Slip Resistance on Walking/Working Surfaces, suggests a slip-resistance value of 0.50 for dry occupational walking surfaces as measured according to ASTM standards. This value is the most commonly cited for a surface to be considered slip resistant (Rhoades and Miller 137+; Sacher 52+). Depending on the task involved, a slip-resistance value less than 0.50 may be adequate, while in other cases, especially where strenuous push and pull tasks are involved, a value greater than 0.50 may be needed.

Figure 2

Average Slip-Resistance Values for Dry Testing



linoleum and VCT, whereas the Mark II found wet terrazzo to be less slip resistant than wet linoleum and VCT. The explanation for this is unclear.

Discussion

Though designed for the same purpose, the slipmeters tested are quite different in structure and operation. Table 4 lists some practical advantages and disadvantages of each device based on the authors' experiences. While this study found the slip-resistance readings of the two machines to be fairly comparable, subtle discrepancies in the readings of the two devices were noted, which may be attributable to these structural and operational differences. The following analyses of the results provide some insight into the implications of the use of these devices under various conditions.

For dry testing, slip-resistance readings were found to be marginally higher (+0.03) for the English XL than the Brungraber Mark II. However, a closer look at the results reveals that there are a few surfaces for which this may not be true. For example, the XL did not achieve significantly higher slip readings than the Mark II on textured surfaces such as quarry tile or linoleum. This may be attributable to the greater contact area between the test foot of the Mark II compared to that of the XL. A large test foot, it seems, may be more likely to "catch" on raised portions of a textured tile, thus preventing slippage. So, while the English XL may generally achieve slightly greater slip readings on dry surfaces, it should be noted that textured surfaces may be an exception.

With regard to wet testing, no significant difference was found in the readings of the two devices. However, the Brungraber Mark II did have slightly higher slip readings on textured surfaces than the English XL. As noted, this could be attributable to the greater contact area between the Mark II test foot and the test surface.

While the slip-resistance readings (both wet and dry) of the Brungraber Mark II were fairly comparable with those of the English XL when the grooved foot was used on the Mark II, it does not appear that this would have been the case had the ungrooved foot been used. Used in conjunction with the grooved foot, the Mark II yielded significantly higher readings for both the wet and the dry condition than the same device used in conjunction with the ungrooved foot. For the wet test condition, the slip-resistance values attained by the smooth foot were found to be extremely low. This was not an isolated finding, as Chang's (303+) results also document this phenomenon. Chang reports that the Brungraber instrument yielded a slip resistance of less than 0.1 on wet quarry tile.

An explanation for this finding may lie in the dynamics of this device. During its operation, the entire test foot contacts the test surface at once. As a result, it seems possible for a small amount of water to get trapped between the foot and surface, causing the test foot to hydroplane. Using a grooved test foot seems to overcome this problem because water from the test surface is likely channeled into the grooves at the time of initial contact, allowing the test foot to make better contact with the surface material. Although the grooved foot is obviously preferred for slip-resistance measurements, it is possible that the hydroplaning phenomenon of the ungrooved test foot might be similar to shoe sole/walking surface interactions in certain slip-and-fall situations.

The smooth Neolite® test foot on the English XL does not appear to exhibit this hydroplaning phenomenon. The explanation for this seems to lie partially in the dynamics of the devices. Unlike the Mark II, the test foot on the English XL strikes the test surface at an angle so that the edge of the circular foot strikes the surface before the entire foot makes contact with the surface. This movement pattern appears to displace excess liquid that could otherwise result in hydroplaning.

Conclusion

Although previous studies have been performed to compare the performance of alternative testers, this is the only known published data that directly compares these relatively new measurement devices across a wide range of floor surfaces. This study confirms that both testers overcome the problem of adhesion (also called "sticktion") common among dragsled testers. Other testing equipment and methods sometimes yield such skewed readings on wet surfaces that the resulting slip-resistance values would be higher for wet surfaces than for dry surfaces. In this study, the reduction in slip resistance for surfaces when they become wet is approximately 0.44 (from 0.93 dry to 0.49 wet) for the representative floor surface materials tested. Thus, the tested devices provide measurements consistent with the common-sense observation that floors are less slip-resistant when wet.

Although this study is not a substitute for continuing efforts of the ASTM F-13 Committee to assess the English XL and Brungraber Mark II, it nevertheless shows that the slip-resistance readings they produce are generally comparable under both dry and wet conditions, so long as the Mark II is used with a grooved test foot. This means that competent SH&E professionals can now measure slip resistance in the field and assess, for example, slip resistance under wet conditions afforded by alternative floor treatments, finishes or maintenance methods.

Of course, the ability to take measurements does not address the issue of interpreting the data taken with these devices using the Neolite® sensor material. A leather sensor is traditionally used with the James Machine to assess whether or not a floor finish achieves at least a 0.50 static coefficient of friction and can be marketed as "slip resistant" (Sacher 52+; ASTM F2047-93). However, leather is not considered suitable for wet testing because it is highly water absorbent and its physical properties permanently change as it absorbs water. When Neolite® is used with portable slip testers, should the same 0.50 criterion still apply? Should this criterion apply under both dry and wet conditions? These are complex research issues that involve the relationship between

How Can Friction Be Increased on Existing Floors?

Solicit technical support from floor the finish manufacturer. The manufacturer should observe floor maintenance procedures to confirm that its products are being used properly, then help troubleshoot why slip resistance may not be at the desired level.

Consider "head-to-head" testing of floor finishes. Ask vendors to perform head-to-head testing at the site to compare slip-resistance characteristics of various floor finish products on the market.

Solicit technical support from the floor manufacturer/installer. The floor manufacturer/installer may be in a good position to make recommendations for minimizing the slip-and-fall potential of the floor.

Consult the building's architect who specified/designed the floor. The architect may have experience with alternative products or methods.

Reduce the level of contaminants. Consider increasing the frequency of housekeeping inspections. Increased use of mats and runners may be warranted. When used, be sure that mats and runners are in good condition to avoid introducing tripping hazards.

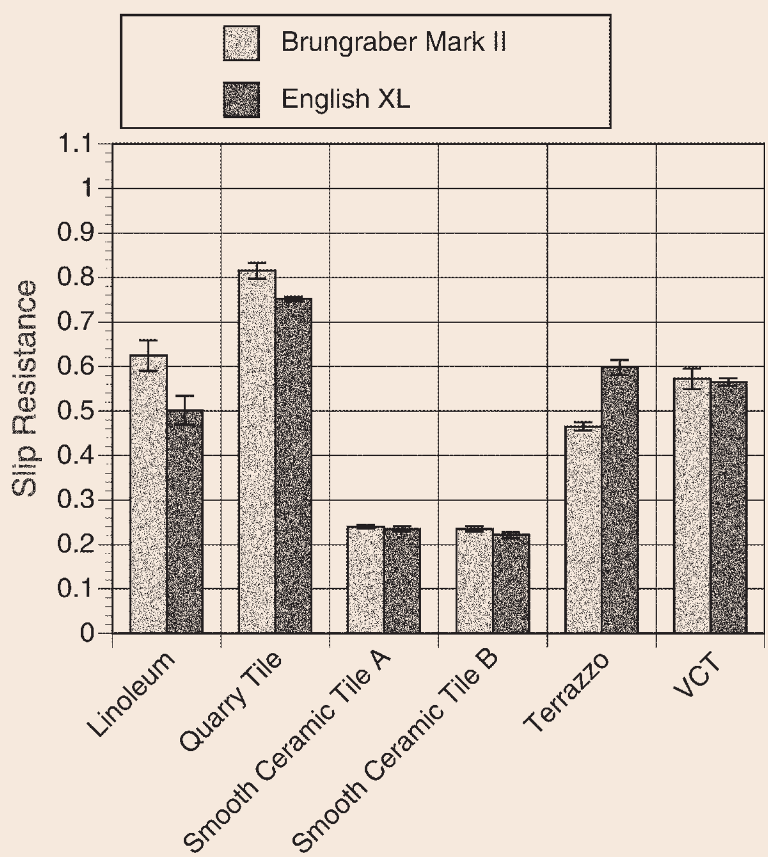
Consider footwear. Footwear varies significantly in the traction provided. In some cases, restricting employee footwear is a practical solution to slip-and-fall injuries.

Consult with others with similar flooring and traffic. This may help determine how others have addressed similar problems.

Change the floor surface. If these other recommendations do not adequately address concerns related to slip resistance, then the site may need to consider a significant change in the floor surface.

Figure 3

Average Slip-Resistance Values for Wet Testing



Perhaps the most-practical use of these two slipmeters is the assessment of alternative floors, floor finishes and maintenance practices.

Table 3

Floor Surface Materials in Rank Order According to Slip Resistance

Both Devices (Dry)	Brungraber Mark II (Wet)	English XL (Wet)
Vinyl tile (linoleum)	Quarry tile	Quarry tile
Smooth ceramic tile (B)	Vinyl tile (linoleum)	Terrazzo
Smooth ceramic tile (A)	Vinyl composite tile (VCT)	Vinyl composite tile (VCT)
Quarry tile	Terrazzo	Vinyl tile (linoleum)
Terrazzo	Smooth ceramic tile (A)	Smooth ceramic tile (A)
Vinyl composite tile (VCT)	Smooth ceramic tile (B)	Smooth ceramic tile (B)

Note: Surfaces ranked from most to least slip resistant top to bottom.

Table 4

Advantages/Disadvantages of the Devices Tested

	Brungraber Mark II	English XL
Advantages	Large test foot size affords testing of shoe heels. Only gravity is needed for actuation. Sturdy, rigid frame.	Relatively lightweight and compact. Relatively fast and efficient operation. Operator certification course offered by manufacturer.
Disadvantages	Relatively heavy and bulky. Test foot has tendency to bounce when trigger-actuated. Standard ungrooved test foot may hydroplane during wet testing.	Test foot size smaller than needed to test many shoe heels. Requires CO_2 cartridges for actuation. Frame flexes noticeably under heavy load.

the amount of slip resistance required for a specific task versus the slip resistance afforded by a surface under a given set of shoe sole and contaminant conditions (Rhoades and Miller 137+). On the more practical side, standards related to best practices are evolving, with ASSE taking a lead role as secretariat of ANSI A1264.2, Standard for the Provision of Slip Resistance on Walking/Working Surfaces.

Perhaps the most-practical use of these two slipmeters is the assessment of alternative floors, floor finishes and maintenance practices under wet as well as dry conditions. Beyond assessing floors, even greater benefit can be achieved by selecting shoes with appropriate slip-resistant tread and shoe sole material characteristics. With the development of better measurement devices, SH&E professionals will be able to select better floors, floor finishes and shoes that—combined with good housekeeping—can help reduce slip-and-fall injuries. ■

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Endnotes

[1]Available from Slip-Test, P.O. Box 387, Spring Lake, NJ 07762.

[2]Available from William English Inc., 20500 North River Rd., Alva, FL 33920.

[3]Available from Smithers Scientific Services Inc., 425 W. Market St., Akron, OH 44303.

[4]Available from Controls International, 3502 W. Devon Ave., Chicago, IL 60659.

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