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Comparison of Floor Surface Slip Test Results from the English XL and BOT-3000E Tribometers

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Abstract: There are a variety of tribometers marketed to measure the slip resistance of floor surfaces, including the more recently evolved "robotic" slip meters, such as the BOT-3000E digital tribometer. The purpose of this study was to compare the measurements taken using the robotic dragsled-style BOT-3000E digital tribometer and the biofidelic English XL variable incidence tribometer. Tests were conducted across a variety of floor surfaces under both dry and wet conditions. For testing using the BOT-3000E, four different test methods were used: ANSI A137.1, ANSI B101.1, ANSI B101.3, and the dry static coefficient of friction method. For the English XL, the dry test method and the wet test method specified by the manufacturer were used. The results for the two tribometers and multiple test methods are reported and demonstrate that slip resistance measurements can be significantly affected by the tribometer and test method used.

1. Introduction

There are a variety of tribometers marketed to measure the slip resistance of floor surfaces, including the more recently evolved "robotic" slip meters, such as the BOT-3000E digital tribometer. Two slip meters, the biofidelic English XL and the robotic dragsled-style BOT-3000E, were used to measure the slip resistances of several different floor surfaces under wet and dry conditions, and their results compared. A previous study comparing the English XL to another tribometer found the two devices produced similar results for a variety of floor surfaces under both wet and dry conditions (Grieser, Rhoades, & Shah, 2002).

2. Methods

2.1 Study Design

This experiment was conducted under laboratory conditions and used a complete factorial design in which the independent variables were testing device, floor surface material, and floor surface condition (Table 1). The dependent variable was slip resistance. Measurements were taken in random order, except that all dry measurements preceded all wet measurements.

Table 1. Independent variables examined.

Testing Devices	Floor Surface Materials	Floor Surface Conditions
English XL	Painted Deck Wood	Dry
BOT-3000E	Painted Concrete	Wet: Distilled
	Unpainted Concrete	Wet: 0.05% soap
	Glass	Wet: 0.1% soap
	VCT	
	Ceramic Tile	

2.2 Testing Devices and Equipment

Two devices were used to measure slip resistance in this study. The English XL Variable Incidence Tribometer (Figure 1) is a biofidelic slipmeter suitbable for both wet and dry measurements (Grieser et al., 2002; ANSI/ASSE TR-A1264.3-2007). The English XL uses a flat circular test foot with a diameter of 1.25 inches made from Neolite® rubber. The contact surface of the factory-supplied test foot is composed of a 1/8-inch thick piece of test-grade Neolite® rubber, a material found to provide reliable and repeatable slip resistance data in a variety of conditions (Grieser et al., 2002; ANSI/ASSE TR-A1264.3-2007). The tribometer was outfitted with a sequencer, which is designed to consistently actuate the test foot for 0.5 seconds upon each depression of the palm button, thus reducing variability associated with inconsistent human performance related to actuation duration.

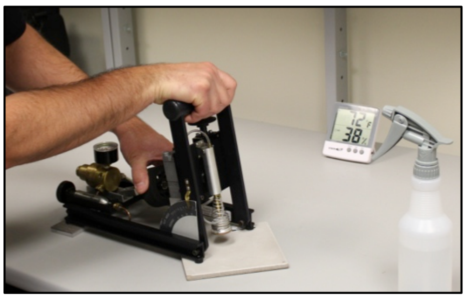

Figure 1. English XL tribometer, shown with calibration tile.

Figure 2. BOT-3000E.

The BOT-3000E (Figure 2) is a self-propelled portable digital tribometer using square convex test feet, called sliders, made from Neolite® rubber (used in dry testing) and styrene-butadiene rubber (SBR) (used in wet testing). The BOT-3000E can be programmed to perform static and dynamic coefficient of friction tests under both wet and dry conditions. Prior to testing, each device was factory calibrated, and calibration was verified according to their respective user guides before each day of testing.

2.3 Preparation of Floor Surfaces

Six test surfaces were prepared for this study: ceramic tile, VCT, glass, unpainted concrete, painted concrete, and painted deck wood. A 12x12 inch (nominal) smooth ceramic tile, a 12x12 inch VCT tile, a 12x18 inch pane of ¼-inch thick glass, and a 16x16x2 inch (nominal) concrete patio stone were procured from home improvement stores and were not materially altered for purposes of this study. The painted concrete test surface was prepared using a 16x16x2 inch (nominal) concrete patio stone. A concrete and masonry bonding primer and concrete floor paint were applied according to their instructions. Paint color was not altered.

The painted deck wood surface was prepared using standard 5/4” x 6” (nominal) treated deck wood. An exterior multi-surface primer and sealer was applied to the deck wood area, followed by an exterior paint. A multi-surface primer and sealer and the paint were marketed for exterior application and applied according to their instructions. Paint color was not altered. The painted concrete and wood surfaces cured for several months indoors at room temperature. Prior to testing, each test surface was rinsed thoroughly, washed and scrubbed with dish detergent to remove any contaminates, and rinsed thoroughly again. Each test surface was air dried overnight before testing began.

2.4 Procedure

Test runs were randomized by floor surface and testing device, though floor condition was tested in order of increasing levels of contamination: dry, distilled water, distilled water with 0.05% soap solution (BOT-3000E only), and distilled water with 0.1% soap solution (BOT-3000E only).

Testing was performed according to the respective user guides of each tribometer, and four repetitions were performed for each test surface and condition. The four repetitions were performed in different nominal compass directions (North, East, South, West – order performed according to each tribometer’s user guide) relative to the floor surface.

All dry and wet measurements were performed in the same area of each test surface. The test areas were chosen to avoid substantial surface irregularities (e.g., unusual asperities, splits or knots in wood, etc.). All measurements were taken at standard room temperature (72°F), and the humidity ranged from 42% to 48% during dry testing.

2.4.1 English XL Procedure

For the English XL tribometer, each repetition consisted of a series of "strokes," 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 approximately 0.01 until a slip occurred. The recorded slip resistance value was that at which a complete slip first occurred. A minimum of three non-slip strokes was required prior to a slip in order to record a slip resistance value. If the slip occurred without at least three non-slip strokes preceding it, the test was repeated beginning at lower mast angle until the slip occurred after the third non-slip stroke. During dry testing, the test foot was sanded after each slip using The Sander® (Figure 2) with 180 grit sandpaper in a circular motion five times clockwise. During wet testing, the test foot was not sanded after each slip but was only sanded if it became noticeably scored.

2.4.2 BOT-3000E Procedure

For the BOT-3000E, each repetition consisted of placing the device on the floor surface with enough space to allow it to travel forward while performing four short skids of the test foot against the floor surface (the skids were automatically averaged). Once the BOT-3000E wasin position, a coefficient of friction test was selected from the test menu, and it began its autonomous slip resistance measurement for a given nominal compass direction. On occasion, the BOT-3000E cleared its screen before the final result could be recorded. In such cases, the test was repeated.

During dry testing, measurements were taken using the BOT-3000E's preset dry SCOF test setting. The BOT-3000E test foot was sanded five rotations following each dry measurement using its provided sanding device.

BOT-3000 slip resistance measurements were performed under three wet conditions, each specified by one of three ANSI test methods. First, the floor surface was contaminated with distilled water and was slip tested according to the ANSI B101.1 test method. Next, a 0.05% concentration soap solution was prepared with distilled water and liquid soap provided in the BOT-3000E test kit. This solution was used to contaminate the floor surface and was tested according to the ANSI A137.1 test method. Finally, a more concentrated 0.1% soap solution was prepared, and the slip resistance was measured according to the ANSI B101.3 test method.

Table 2. BOT-3000E ANSI Test Methods: Wet.

Test Method	Test Foot	Soap Solution
B101.1*	Neolite	Distilled water
A137.1	SBR	0.05% soap
B101.3	SBR	0.1% soap

* Only one of three test methods that uses static test.

3. Results

3.1 Dry Slip Resistance Measurements

The mean slip resistances as measured by the English XL and BOT-3000E under dry conditions are shown in Figure 3. The results showed that for most of the floor surfaces tested, the BOT-3000E measured a higher slip resistance than the English XL. Ceramic tile was the only surface on which the English XL measured a higher slip resistance than the BOT-3000E. A t-test was conducted to determine whether the measured slip resistances were significantly different between the English XL and BOT-3000E. The results shown in Table 3 demonstrate that the slip meter had a significant effect on the measured slip resistance for most of the floor surfaces tested.

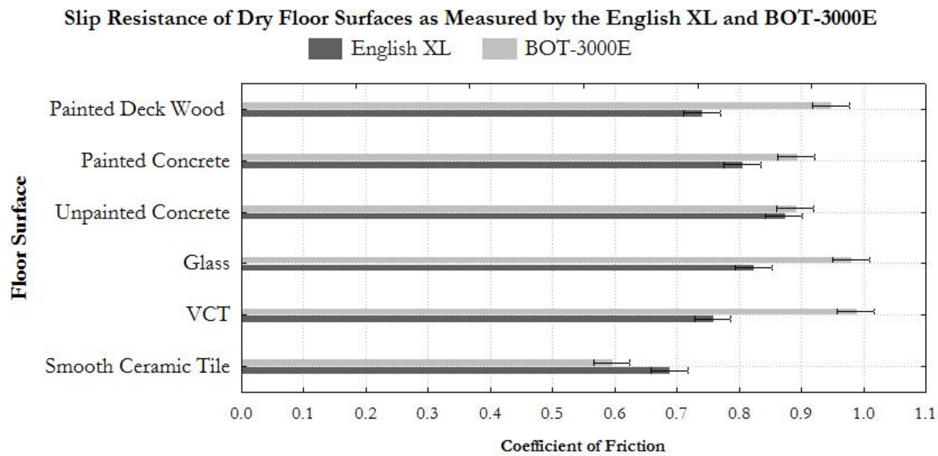

Figure 3. Slip resistance of dry floor surfaces as measured by English XL and BOT-3000E.

Table 3. T-test results comparing slip resistance measurements by English XL and BOT-3000E under dry conditions.

Floor Surface Materials	Difference of Means (BOT - English)
Painted Deck Wood	0.21*
Painted Concrete	0.09*
Unpainted Concrete	0.02
Glass	0.16*
VCT	0.23*
Ceramic Tile	-0.09*

*Significant at $p \leq 0.05$

3.2 Wet Slip Resistance Measurements

The mean slip resistances as measured by the English XL and BOT-3000E under wet conditions are shown in Figure 4. The results showed that slip resistance measurements for certain floor surfaces can vary by testing device and method.

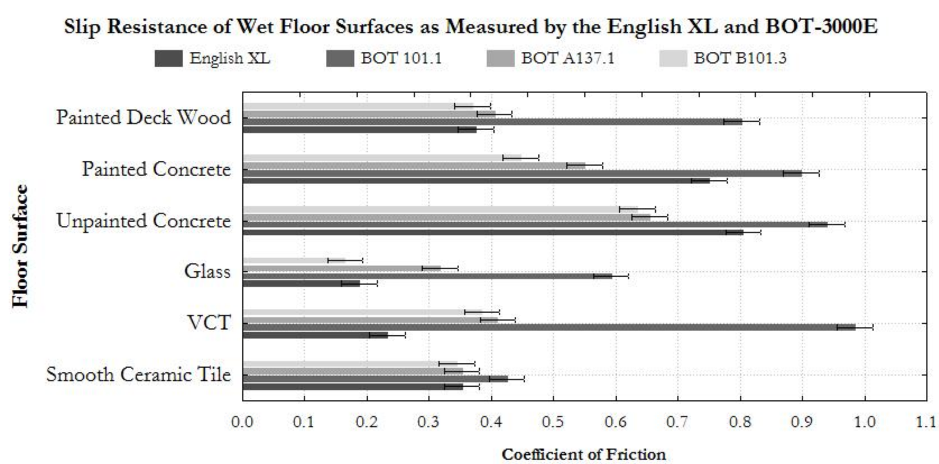

Figure 4. Slip resistance of wet floor surfaces as measured by English XL and BOT-3000E.

3.3 Slip Meter Test Method Comparisons

The slip resistances measured by the English XL were compared with the three BOT-3000E test methods—B101.1 (distilled water), A137.1 (0.05% soapy solution), and B101.3 (0.1% soapy solution)—using three separate factorial ANOVA.

The results showed that the English XL and BOT-3000E B101.1 test methods were significantly different across the floor surfaces tested ($p < 0.05$), where the BOT-3000E B101.1 test method produced significantly higher measurements on each floor surface.

The results showed that the English XL and BOT-3000E A137.1 test methods were not significantly different across the floor surfaces tested ($p = 0.790$). However, the two test methods were significantly different for four of the six floor surfaces tested, but balanced such that when analyzed across all floor surfaces, they were not statistically different.

The results showed that the English XL and BOT-3000E B101.3 test methods were significantly different across the floor surfaces tested ($p < 0.05$). The BOT-3000E B101.3 test method produced a lower mean slip resistance, though three of the six floor surfaces tested were not significantly different from the English XL.

Additionally, the slip resistances measured by the BOT-3000E B101.3 and A137.1 test methods were also compared using a factorial ANOVA. The results showed that the two test methods were significantly different across the floor surfaces tested ($p < 0.05$), where the A137.1 test method produced significantly lower slip resistance measurements for two of the six floor surfaces tested.

As expected, the slip resistances measured by both the English XL and BOT-3000E B101.1 test method were significantly ($p < 0.05$) lower under wet conditions than dry.

4. Discussion

4.1 Dry Slip Resistance

The results of this study show that, in a number of cases, different slip meters can produce statistically different results when measuring the same surfaces. For four out of six surfaces, the BOT-3000E mean slip resistance was significantly higher than that of the English XL. The BOT's overall mean slip resistance was also significantly higher than the English's. However, because the mean slip resistances are typically so far above 0.50, the differences observed with this particular set of floor surfaces are unlikely to produce any material difference in the determination of whether the surface is considered slip resistant under dry conditions.

4.2 Wet Slip Resistance

Not surprisingly, the BOT-3000E results show that slip resistance decreases with increasing soap concentration. It should be noted that the B101.1 test method is a static coefficient of friction test using distilled water. Had a dynamic coefficient of friction test been specified by B101.1, it is expected that the B101.1 data would be more in line with the A137.1 and B101.3 tests, which are both dynamic. The B101.1 results are often negatively impacted by the well-documented sticktion phenomenon that artificially inflates the results of static COF testing performed under wet conditions (Di Pilla, 2010; ANSI/ASSE TR-1263-2-2007). For example, for half of the surfaces, the BOT-3000E B101.1 test method was the only one that found the surfaces to be slip resistant when wet.

Based on statistical analysis of combined slip resistance measurements across all floor surfaces tested, it might appear that the results of the English XL and BOT-3000E A137.1 test method could be considered equivalent. However, the two provided similar results for only two of the six surfaces tested (painted deck wood and smooth ceramic tile). It is not apparent why these floor surfaces yielded similar results or why there was no apparent pattern among the differences on the painted concrete, unpainted concrete, glass, and VCT floor surfaces.

The BOT-3000E on some surfaces produced puzzling results. For example, the B101.3 test method was the only test method that found wet painted concrete to not be slip resistant (i.e., < 0.50). Additionally, VCT was one of the smoothest surfaces tested, but the B101.1 test method found it to be the most slip resistant of all. Curiously, the floor surface that resulted in the most consistent agreement among the four test methods was the smooth ceramic tile.

The English XL, in general, produced results consistent with expectations given floor surface characteristics.

5. Conclusions

The English XL and BOT-3000E devices fundamentally measure different friction-related phenomena. The BOT-3000E is a robotic drag sled device. It measures static (B101.1) and dynamic (A137.1 and B101.3) coefficient of friction (Regan Scientific Instruments, 2013) and it has been stated that its results are not intended to predict the likelihood of a person slipping (Tile Council of North America, 2012). The English XL measures neither static nor dynamic coefficients of friction. Rather, the English XL's test foot is designed to apply force to a floor surface at a velocity and angle similar to a human's heel during ambulation. Therefore, it is not surprising that the two devices generally yielded different results under both wet and dry conditions.

6. References

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