



METROLOGY OF

# ***Pedestrian Locomotion and Slip Resistance***

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# ***Metrology of Pedestrian Locomotion and Slip Resistance***

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# Foreword

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The Symposium on Metrology of Pedestrian Locomotion and Slip Resistance was held at the ASTM Headquarters, West Conshohocken, Pennsylvania, on 5 June, 2001. ASTM International Committee F13 on Safety and Traction for Footwear served as its sponsor. The symposium co-chairmen and editors for this publication were Mark I. Marpet, St. John's University, and Michael A. Sapienza, Congoleum Corporation.

# Overview

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## Background

Fall accidents rank number one or two (depending upon what statistic one is using) in the harm, e.g., cost of injury, number of deaths, etc., from accidental causes. Researchers have estimated the cost of slip-precipitated accidents in the billions of dollars per year; there is evidence that slip accidents may be underreported; and it is expected that the number, cost, and harm from slip accidents will rise in the United States as the population ages. Fall accidents that occur as a result of not enough friction available between the floor and shoe bottom for the pedestrian to ambulate without slipping are responsible for a great number of walkway accidents. For this reason, characterizations of how much friction pedestrians require to ambulate and how much friction is available between the foot or shoe bottom and the walkway surface are of great import.

On June 5, 2001, ASTM International's Committee F-13 on Safety and Traction for Footwear sponsored a Symposium on the Metrology of Pedestrian Locomotion and Slip Resistance. It was held at ASTM International headquarters in West Conshohocken, Pennsylvania. Michael Sapienza and I co-chaired that symposium.

The focus of the Symposium on the Metrology of Pedestrian Locomotion and Slip Resistance is clearly spelled out in its name. The objective of the symposium was to gather the latest research findings concerning both how much friction pedestrians require during ambulation and how to measure best the friction available between the walkway surface and the shoe bottom. In the past, a number of symposia and two STPs have covered this and nearby ground.<sup>1</sup> Since these STPs have been released, there have been many significant developments in the areas of locomotion biomechanics and of walkway-safety tribology. Thus, it is time to take stock again. The stated objective in the symposium's call for papers, Sapienza wrote, was—

to improve pedestrian safety by increasing the current understanding of slip resistance measurements, standards, and criteria, and their application to pedestrian locomotion. This symposium [will] present the latest findings and most up-to-date information on related areas, to focus on directions for future research, to discuss the need for consensus performance criteria, and to review existing information on the causes and prevention of slips and falls. This information will enable the production of meaningful test methods, standards, and practices that will result in a real improvement in pedestrian safety.

At the symposium, twelve papers, from authors around the globe, were presented; a panel discussion was then held. From the twelve presentation abstracts, ten research papers were

<sup>1</sup> Specifically, ASTM STP 649 (Anderson and Senne, Eds., *Walkway Surfaces: Measurement of Slip Resistance* (1978)) and STP 1103 (Gray, Ed., *Slips, Stumbles, and Falls: Pedestrian Footwear and Surfaces* (1990)). These two STPs are must-reads for anyone involved in the friction-related aspects of walkway safety. Related STPs, which may be of real interest to some researchers, include ASTM STP 1073 (Schmidt, Hoerner, Milner, and Morehouse, Eds., *Natural and Artificial Plating Fields: Characteristics and Safety Features* (1990)) and ASTM STP 1145 (Denton and Keshavan, Eds., *Wear and Friction of Elastomers*, (1992)).

written and submitted, made their way through the peer-review and revision process, were ultimately accepted, rewritten yet again, and appear in this STP.

## The Papers

These papers explore in considerable depth important aspects of the measurement of pedestrian-locomotion forces (characterized by what is variously called the *required friction*, the *utilized friction*, and the *friction demand*), the measurement of walkway/shoe-bottom friction (the *available friction*), and standards-development issues in walkway/pedestrian safety.

The ten papers fall into those three broad categories: (1) Biomechanics of Ambulation, (2) Walkway-Safety Tribometry, and (3) Walkway-Safety Standards Development.

In the Biomechanics of Ambulation area are three papers: by Burnfield and Powers, by Lockhart et al., and by Kim and Smith. The first two papers explore different aspects of the relationship between age and pedestrian ambulation, significant because fall accidents exact a disproportionate toll on senior citizens. Burnfield and Powers' paper concentrates upon the required friction used by pedestrians of various ages. Lockhart's paper looks at the age-related differences in the way that pedestrians either slip or attempt to recover from a slip. Kim and Smith's paper explores the matter of shoe-bottom wear and its effect upon friction demand; it has significant ramifications in the area of test-foot standardization.

In the tribometry category are four papers. Two of the four, viz., the papers of Brungraber et al. and Nagata, both present novel ways of measuring friction. Brungraber's paper explores the design of a simple, inexpensive ramp that can test the friction available between a whole shoe and a walkway-surface sample. Nagata's paper analyzes the dynamic friction available between a crash-test-dummy roofer surrogate and a sloped roof as a function of the surrogate roofer's acceleration down the roof. The other two papers explore issues in tribometric testing of wet surfaces. Medoff et al.'s paper explores issues in tribometer test-foot design, specifically, the hydrodynamic effects of machining grooves in the test-foot. Here, the authors find that PIAST and VIT instrument results can be made to converge by appropriate test-foot grooving. Smith's paper looks at wet-surface tribology and its relation to a phenomenon that some call "stiction."

There are three standards-development papers. Fendley's paper explores just why it has been *so* difficult to achieve consensus in the development of walkway-safety standards, a difficulty that goes *far* beyond technical issues. My paper discusses both how clinging to too-limiting abstractions of friction can distort the standards-development process, and discusses the rank-comparison approach proposed by the ASTM International Board of Director's Task Group that presently oversees ASTM Committee F-13. This rank-comparison approach is inherently nonproprietary; it will hopefully allow test results from different types of tribometers to be made comparable.

Finally, Bowman et al.'s paper, which explores issues in rank-order comparison of tribometric test results, concludes that the development of a robust ranking system, i.e., one in which rank-orders are preserved across different tribometers and tested materials, is a non-trivial undertaking.

## Future Directions

As much as has been accomplished in increasing our knowledge of how and why pedestrians slip and fall, much still needs to be accomplished; these paragraphs could not hope to cover it all.

In the biomechanics-of-locomotion area, there are a number of fruitful areas. Researchers need to continue the work already in progress, including characterizing the friction required for ambulation activities not yet characterized, analyzing age and gender differences not yet analyzed, and honing in on exactly what in the gait determines whether or not a slip-precipitated fall will occur. Work needs to be done in characterizing the friction requirements as a function of the various ambulatory handicaps, e.g., different amputations, physical or neurological conditions, and so forth, and of different ambulatory aids (obviously, these two matters interrelate). This information is needed to ensure that any friction thresholds that are set by standard actually increase pedestrian safety and, at the time, do not needlessly burden the manufacturers of shoes, flooring materials, and floor polishes. Finally, the physical parameters of heelstrike and foot rolldown need to be better characterized, viz., the distribution across time and subjects (including age-, gender-, and impairment-related differences) of horizontal-, vertical-, and angular-foot velocities, the area of shoe-bottom contact, the location of the center of pressure, and the force and pressure distributions.

In the walkway-safety-tribometry area, it would be naïve to think that instrument development has stopped. Importantly, any new tribometric instruments developed need to take into account the important heelstrike and rolldown parameters, many of which are not yet adequately characterized (See the last sentence in the paragraph just above.) Test-foot material, configuration, and preparation issues are actively being worked upon, and need more work. These issues relate to short- and long-term stability of the test feet and procedures to ensure repeatability and reproducibility of results. The statistical analysis of tribometric data is an area ripe for development. Questions abound: is the mean the best summary statistic to ensure pedestrian safety? Should there be a minimum number of test determinations required? One question, the one that Medoff et al.'s paper addresses, is clearly ready for prime time: What is the optimal groove pattern in a given instrument's test foot, to ensure that the test best replicates conditions at the point in the gait cycle where pedestrians are most likely to slip?

In the area of research specifically directed to walkway-safety-standards development, I would like to mention the research and round-robin testing being conducted under the aegis of the Board of Directors F-13 Task Group, chaired by Donald Marlowe. That task group has been and is investigating the rank-order consistency of various test-foot/test-surface combinations. It is a painstaking, time-consuming effort; if successful, it will allow an instrument-independent approach to walkway-safety test-result comparisons.

There is another field that has a potentially large payoff in pedestrian safety. That is in the field of shoe design, which while not discussed in this STP, is certainly under the responsible charge of ASTM Committee F-13 on Safety and Traction for *Footwear* [emphasis mine]. Let me briefly mention two areas that I believe are worth exploring. Firstly, shoe-bottom tread designs that will allow proper drainage of water and other contaminants while operating in a real-world environment, where shoe-bottoms wear, get all sorts of noxious substance on them, have to be affordable, and must not violate fashion constraints. Secondly, it might be fruitful to explore for use as shoe-bottom materials those resilient materials that have an increasing friction with velocity; this could allow the shoe bottom itself to help snub a slip. This is not a new idea: D. I. James discussed this matter in the 1980s.

## Disclaimer

The classification of the papers into one of three discrete categories ((1) Biomechanics of Ambulation, (2) Walkway-Safety Tribometry, and (3) Walkway-Safety Standards Development) is somewhat arbitrary because pedestrian/walkway safety is inherently multidisciplinary. Many of the papers in this STP overlap the different categories. Some examples:

- Bowman et al.'s paper was clearly directed towards the need for care in rank-based tribometric-results analysis, so I placed it in the third area. Because of the rich set of experimental results contained in that paper, it could have easily fit into the second.
- Kim and Smith's paper concerning friction changes as a result of heel wear, because of that paper's important implications for tribometer-test-foot standardization, also could have just as easily been placed in the second category.
- Brungraber et al.'s paper, concerning friction measurement using what they call a step ramp, could have easily fit in the biomechanics-of-ambulation category of papers—as it requires humans to step on the ramp to determine if a slip occurs.

The decision concerning which of the three categories each paper best fit rested solely with me. If you disagree with the classification, please do not think ill of the authors, the reviewers, Sapienza, or anyone at ASTM International. Think ill of me.

Similarly, the one- or two-sentence descriptions of the papers above are mine, and not the authors. So if you think they are off the mark ...

If you read all the papers in this STP, you will see that complete agreement between the papers does not exist. For an in-flux research area like pedestrian-walkway slip resistance, that is not surprising. No attempt has been made to eliminate or reconcile inconsistencies or differences between the papers; that is not the reviewer's function; that is not the editor's function. Rather, that is the function of future research and study. The reviewer's function is to ensure that the methodologies and experimental designs are both appropriate and adequately described, that the results are reasonable, and that the conclusions are not overdrawn. The editor's function is to ensure that each paper is drafted in comprehensible American English and that the graphical presentations of information make sense. Thus and importantly, the research and conclusions in the papers in this STP are the authors', and not the reviewers', the editors', or ASTM International's.

## Thank You

The Symposium and this STP could not have happened without the contributions of many. I could not possibly name all that were involved without going on for pages. Given that, I would like to thank the symposium presenters, most of whom became authors in this STP. Thank you, participants, authors, and co-authors.

ASTM International and ASTM Committee F-13 on Safety and Traction for Footwear sponsored the symposium. ASTM International allowed us to use their headquarters to hold the symposium. ASTM International is publishing this STP. Thank you, ASTM International.

The difference between magazine articles and research papers is the acted-upon contributions of the peer reviewers. For no apparent reason other than their great expertise in the areas of this symposium and their desire to advance this field of knowledge and endeavor, a gaggle of reviewers were drafted (were volunteered, actually) and pressed into service. (Peer reviewing is a classic example of the maxim that no good deed goes unpunished.) The peer reviewers who worked upon the papers contained in this STP clearly knew the import of an ASTM STP in the walkway-safety area, as evidenced by their careful and *constructive* reviews of the submission drafts. It was the peer reviewers' insights, as acted upon by the authors, that turned the submission drafts into the papers that you see in this STP. Thank you, peer reviewers.

Six need mention by name. I would like to thank Mike Sapienza, the Research Director at Congoleum and my co-chair, who was instrumental and essential in getting the Symposium off the ground. Simply put, without Mike, none of this would have happened. Donald Marlowe was the Chairman of the Board of ASTM International and was and is the Chairman



of the Board of Directors Task Group overseeing and supporting Committee F-13's standards-development efforts. Don's support helped get this project off the ground. David Fleisher, who was at the time the chairman of Committee F-13, first suggested the need for this symposium, then *pushed* us to get started, and then gave invaluable assistance to get it off the ground. Mary McKnight at the National Institute for Standards and Technology is a member of ASTM International's Committee on Publications; she investigated the feasibility of our STP proposal and, ultimately, gave us the go-ahead. I know how carefully she researched our proposal; by the time I spoke to her, she had literally checked the STP actors and the proposal out with just about everybody who was anybody worldwide in the field of walkway safety. This level of vetting is what gives ASTM STPs their great credibility. Scott Emery at ASTM International painstakingly copy-edited all the papers into proper format, so that the look was both uniform within the STP and similar to other STPs. When Scott got done with the edits to my draft, there was more in the way of notes to the paper than there was paper. The other papers received similar attention. Finally, I would like to thank Crystal Kemp at ASTM International for her help and support. Crystal was my interface with ASTM International's publications group. I could not have asked for a better partner in this endeavor. Thanks, Crystal; I would work with you again in a heartbeat.

Thank you Mike, Don, Dave, Mary, Scott, and Crystal.

*Mark I. Marpet*

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