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# TCNA TILE INITIATIVE



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# RESEARCH SUPPORTING AN ANSI AMERICAN NATIONAL STANDARD FOR SLIP RESISTANCE

By Eric Astrachan

The method for measuring the coefficient of friction (COF) of ceramic tiles is specified in Section 9.6 of the American National Standard Specifications for Ceramic Tile, ANSI A137.1. The method changed in 2012 from the ASTM International test method C1028, which measured static coefficient of friction (SCOF), to the test protocol described in Section 9.6, which measures dynamic coefficient of friction (DCOF).

The transition from SCOF to DCOF has been well documented<sup>1,2</sup> in previous articles by TCNA noting extensive research done in Germany and at TCNA. This article explains that research in detail. While some articles are referenced that are only available in German, the major research components from Germany are also available in English.

Although the test method described in Section 9.6 was originally written for ceramic tiles, the same general method and the same research underpinning the method are equally applicable to all hard surfaces.

## German Research and Safety Standards

German safety research is a cooperative effort between the government, in the form of the German Social Accident Insurance [Deutsche Gesetzliche Unfallversicherung (DGUV)], and a host of universities, each focused on a particular area of public safety. In the field of pedestrian floor safety, the University of Wuppertal [Bergische Universität Wuppertal] has many decades of cooperation with the main DGUV research and testing laboratory at the German Institute for Occupational Safety and Health [Institut für Arbeitsschutz (IFA)] in Sankt Augustin, Germany. Their joint efforts led to the creation of German national standards—commonly referred to as DIN (Deutsches Institut für Normung e.V.) standards—for testing and



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He is the Convener of ISO TC-189 Working Group 2 on ceramic tile standards, an elected officer of ASTM's F13 Committee on Pedestrian/Walkway Safety and Footwear, and active on several other industry technical committees.

He is an Executive Committee member of the Board of the Ceramic Tile Education Foundation, serves on the Board of the Porcelain Tile Certification Agency, and is on the Board of Governors of the international trade show Coverings. He is also a recognized industry consultant and keynote speaker for a broad range of industry topics, including product standards, installation, international trade, and slip/fall litigation.

certifying footwear and flooring in the laboratory. These methods, DIN 51130 (“German Ramp Test”) and DIN EN 13287 (“Floor-Shoe Tester”) have been widely used in their respective industries. In the case of the ramp test, the method has been used to make laboratory measurements of flooring for more than 20 years.<sup>3</sup>

Following the development of the German ramp test, research was conducted titled “Experimental Investigation to Determine the Standardized Limit of the Coefficient of Friction for Slip Resistance During Walking,” which was the doctoral thesis of Dr. Stefan Bönig, then a graduate student in Safety Engineering at Wuppertal.

### Dr. Bönig’s Research: Eight Walking Conditions

Using force plates<sup>4</sup> Bönig set out to empirically determine the friction necessary for safely traversing eight walking conditions:

- Walking in a straight line on a level surface
- Walking while turning
- Ascending stairs
- Descending stairs
- Walking across a ramp
- Ascending a ramp
- Descending a ramp
- Coming to a stop

Through statistical analysis of the empirical data he collected, he confirmed a normal distribution of the data and developed confidence limits for each walking condition.

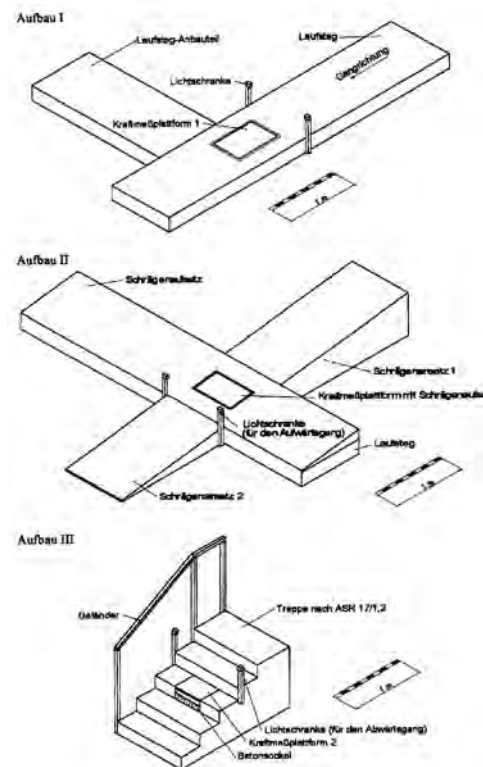
This allowed three important determinations:

1. The necessary friction for each walking condition as a function of DCOF and statistical confidence.
2. A comparison to existing accident statistics to determine the DCOF limit values for each walking condition at which accidents would be reduced for the population as a whole.
3. An evaluation of limit values for each walking condition to meet a conservative assessment of socially acceptable risk.

### Preliminary Tests

Bönig conducted a series of preliminary tests to determine essential and non-essential influencing variables for this study of necessary friction.

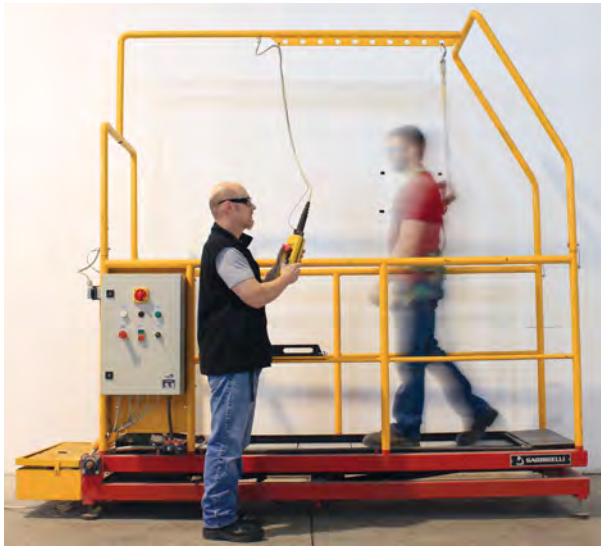
He first looked at the relative significance of different surfaces and shoes. Two measurements were performed for each property combination of eight people, eight floor coverings, and eight shoes. This resulted in 1,024 measurements from which he determined the standard deviations of repeatability and reproducibility per DIN ISO 5725 and the relative impact of each influencing variable. Variability between the test subjects had the largest impact at 97%. The influence of the shoe and floor covering variables was 59% and 43% respectively.



Force plates were embedded into a level surface, a ramp, and on stairs to determine the friction necessary to safely traverse these conditions.

Figure: Dr. S. Bönig, Journal of Work Safety, 2/1997.

# RESEARCH SUPPORTING AN ANSI AMERICAN NATIONAL STANDARD FOR SLIP RESISTANCE



*A German Ramp, similar to the one depicted above, is used in DIN 51130, and in much of the foundational research of Dr. Jens Sebald which underlies the ANSI A137.1 standard. The ramp shown is currently being used for research in the TCNA Laboratory.*

Next he studied the influence of step length and step frequency. Five different step lengths were studied at three different speeds for five subjects with one repeat: a total of 150 measurements. Walking speed was determined to be an influencing variable so the main study was conducted with attention paid to the test subjects walking at their normal personal walking speed.

Bönig next studied load carrying options, specifically the following:

- Walking without load
- Combined lifting and pushing (wheelbarrow)
- Carrying with both arms behind the body with a partner
- Carrying with both arms in front of the body with a partner
- Pushing an object with both arms (cart)
- Carrying with both arms in front of the body
- Carrying on one side to the right of the body
- Carrying on one shoulder

The results showed that the transport operations involving carrying in front of the body with both arms in conjunction with a partner, combined lifting and pushing, and pushing a manual cart with both arms differed significantly from walking without load in terms of the maximum COF requirement. For all other transport operations, no significant differences were observed. However, examination of the mean values showed that the transport operations that differed significantly from walking without load also exhibited a lower mean maximum friction requirement than the friction requirement from walking without load, and thus were also associated with a lower risk of slipping. Therefore, Bönig determined, in comparison to walking without load, the objective risk of slipping was not higher during manual transport operations.

Continuing his preliminary assessment of critical variables for his main study, Bönig determined eight gait models for making a turn with four combinations for stopping to determine the condition requiring the greatest friction.

## **Determining a Test Cohort**

Since age, gender, and body height are correlated with slipping according to Skiba (1983), Skiba, Drapp, and Weider (1988), and James (1983), Bönig created a cohort of fifty test subjects based on random sampling into subsets matching the German population for age, gender, and body height.

He fixed six age and four body height categories and chose the number of test subjects based on the male/female proportion in the general population for each of the six age categories and four body height categories. As an example, he selected six females aged 20 to 30 years and seven males aged 40 to 50 years; he had four females shorter than 1.59 meters and six males taller than 1.84 meters.

## Force Plate Measurements

After constructing three force plate assemblies—one for level walking, one for stairs, and one for ramps—Bönig took 2,700 force plate readings to evaluate the eight walking conditions, including a repeat of the level walking surface using the test subjects' own shoes. Three measurements per surface and per subject were made landing on the right foot and three landing on the left foot for a total of nine surfaces x 50 subjects x 6 measurements, or 2,700 total measurements.

This quantitative assessment was evaluated using Chi-Squared and Kolmogoroff Goodness of Fit tests to confirm that a normal distribution was represented in the data. This was necessary to allow a statistical analysis and an assessment of risk.

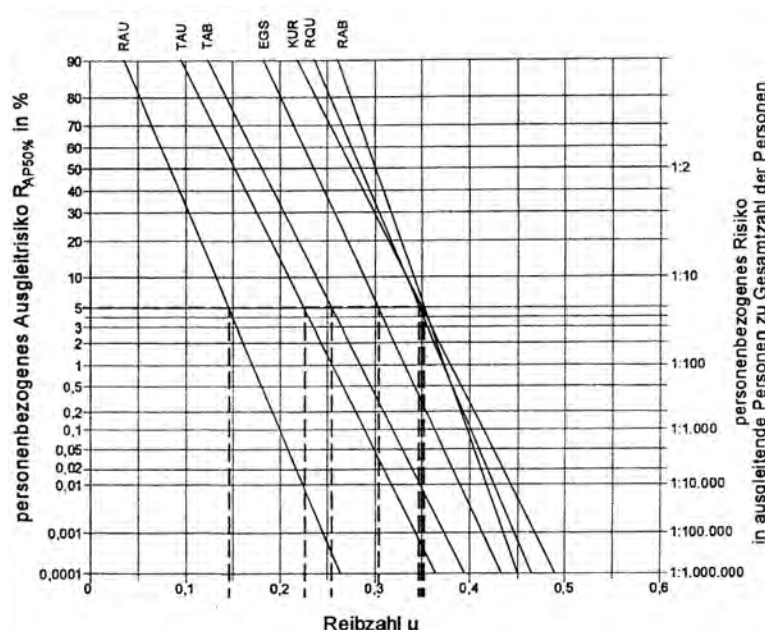
For the eight walking conditions, Bönig determined the maximum necessary friction values within a 95% confidence interval. The required friction for walking in a straight line on a level walkway was 0.31 and the required friction for traversing a ramp was 0.35. The

ascend/descend stairs numbers were 0.23 and 0.26 respectively. He compared his findings, in detail, with many previously published studies and found the mean results to be in line with the ranges of the other studies. For example, a much-cited study in Britain by Harper, Warlow, and Clarke (1961) found the friction requirements for walking in a straight line, with a probability of slipping of 1 per  $10^6$ , to be 0.36.

The figure below presents the risk of slipping for each walking condition except stopping as a function of COF. The values with 95% confidence are marked and the values for a 99% confidence interval can be seen at the intersection with the 1:100 axis.

## Accident Statistics and Social Acceptability

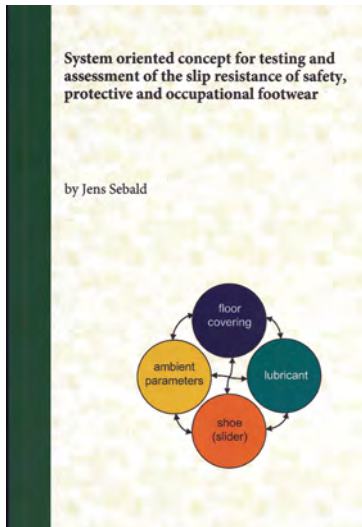
To determine DCOF limit values for each walking condition at which safer conditions would be achieved, Bönig utilized accident data published by the German Federal Government and the Federation of German Statutory Accident Insurance Insti-



**Figure 9.3 from the doctoral thesis of Dr. Stefan Bönig:**  
Determining coefficient of friction from the person-specific risk of slipping as an ergonomic threshold in the form of the 95th percentile.

personen-bezogenes Ausgleitrisiko $R_{AP}$ in %	Person-specific risk of slipping $R_{AP}$ in %
Reibzahl $\mu$	Coefficient of friction $\mu$
personen-bezogenes Risiko in ausgleitende Personen zu Gesamtzahl der Personen	Person-specific risk in number of persons slipping as a function of the total number of persons
RAU	Ascending a ramp
TAU	Ascending stairs
TAB	Descending stairs
EGS	Walking in a straight line on a level surface
KUR	Walking while turning
RQU	Walking across a ramp
RAB	Descending a ramp

# RESEARCH SUPPORTING AN ANSI AMERICAN NATIONAL STANDARD FOR SLIP RESISTANCE



Cover of Dr. Sebald's 2007 PhD dissertation, published by Pro Business in 2009.

tutions [Hauptverband der Gewerblichen Berufsgenossenschaften (HVBG)] that provided data on all accidents in commercial companies in Germany in 1993. This data pool covered 29,688,426 German workers who walked an average of 460,000 straight line steps during the 230 working days that year. An additional 202,400 steps were estimated to have been taken by the average worker over all other walkway geometries for a total 662,400 steps per worker per year.

Based on actual statistics and some assumptions previously validated by Skiba, Drapp, and Wieder in 1988, 238,800 slip accidents occurred in 1993. Of those, 47 were fatalities, 7,458 led to disability pensions, and 23,880,000 near accidents were estimated. Using the worst-case statistical models already developed, and assuming a slip could result in an accident or near accident, that number of near accidents would occur with a straight line walking DCOF of 0.30, a descent of stairs value of 0.31, and a cross ramp value of 0.36.

Simply stated, if the friction available to German workers (i.e. that combination of shoes and flooring) should be greater than the values determined, slip events would decrease.

To determine a measure of social acceptability, Bönig assumed a conservative social acceptance risk factor per Rowe (1977) of  $1 \times 10^{-6}$  fatalities per year (one chance in a million), and a safe walking criteria per person of ten years. Using the accident statistics already described, Bönig calculated the necessary friction pairings to meet this social acceptability criteria: a straight line walking DCOF of 0.39, a descent of stairs value of 0.41, and a turning while walking value of 0.42.

Bönig's study was published in 1996 and was quickly adopted by his academic colleagues at Bergische Universität Wuppertal. It became known as the "Wuppertal Scale" and was subsequently added to the "Bible" of German workplace safety titled "Handbook of Commercial Safety Technology." Bönig's substantial research, subsequent research by Dr. Jens Sebald of Wuppertal, and later research by TCNA together form the basis of Section 9.6 in the ANSI A137.1 standard.<sup>5</sup>

## Research of Dr. Jens Sebald

In 2007, Dr. Jens Sebald completed his research titled "System Oriented Concept for Testing and Assessment of the Slip Resistance of Safety, Protective, and Occupational Footwear." He studied five means of measuring COF, twenty floor coverings, three slider materials, 54 shoes, and three lubricants. The devices included in the study were the following: German Ramp, BST shoe tester, GMG 100, BOT 3000, and the British Pendulum. The floor coverings studied were ceramic and porcelain tile, quarry tile, granite, cast stone, and PVC. The sliders chosen were SBR rubber, Four-S rubber, and Picasso shoe material. The lubricants were motor oil (as used in the DIN 51130 ramp test), water with SLS surfactant, and glycerin.

While the majority of Dr. Sebald's work concerned footwear, including the measurement of footwear slip resistance and relative

comparisons of footwear, Dr. Sebald also assessed the validity of the different friction measurement methods and their suitability for transfer to devices making mobile measurements.

Simply stated, Sebald evaluated the correlation between devices under the large variety of conditions described above.

Comparing the German-engineered/U.S.-made BOT 3000 to the German Ramp, making measurements with an SBR (styrene butadiene rubber) test foot, with motor oil as the lubricant on 12 tile surfaces, Sebald determined a correlation coefficient between the methods of 0.989. Using a water and sodium lauryl sulfate (SLS) solution with an SBR test foot, he found a correlation coefficient between the German Ramp and the BOT 3000 of 0.879. The correlation between the BOT 3000 and the GMG 100 (used in DIN 51131) was 0.926, using water and SLS with an SBR test foot. These correlation coefficients mean the BOT 3000, GMG 100, and German Ramp are tightly correlated.

The same was not true for the British Pendulum, which Sebald demonstrated had a correlation coefficient with the German ramp of 0.687, when tested with SBR on 12 tile surfaces using water with SLS as the lubricant.

## TCNA's Contributions to Measuring COF

In research at TCNA over a five-year period, TCNA studied the following parameters to improve the measurement of COF versus the C1028 method previously referenced in ANSI A137.1, and to assess and improve the repeatability and reproducibility of a BOT 3000 method leading to its inclusion in Section 9.6 of the A137.1 standard:

- Static vs. Dynamic COF
- Deionized water vs. SLS water
- BOT 3000 method vs. C1028 method
- BOT 3000 method vs. British Pendulum method
- BOT 3000 sensor preparation using a TCNA-developed sanding device to eliminate variation from sanding
- Measurement of 300 tile surfaces for SCOF and DCOF, concluding that 0.60 wet SCOF correlated on average with 0.38 wet DCOF.<sup>6</sup>
- Inter-laboratory testing of the method in Section 9.6 using seven different tile surfaces, six laboratories, and three repeats to determine and report the method's reproducibility and repeatability as detailed in the standard.



*The BOT 3000E, shown here, is used for ANSI A137.1, Section 9.6, DCOF testing.*

# RESEARCH SUPPORTING AN ANSI AMERICAN NATIONAL STANDARD FOR SLIP RESISTANCE

## Adoption into Standards

In January 2011, the DGUV in Germany issued its Rule Number 8687 mandating the use of DIN 51131 in combination with a wet DCOF target derived from the Bönig research.

Following the research from Germany, and the research conducted by TCNA, the ANSI accredited A108 standards committee voted to adopt the recommendation from Bönig's research for level interior spaces into the ANSI A137.1-2012 standard. Specifically, the standard sets a required minimum DCOF threshold of 0.42 for surfaces expected to be walked upon when wet, as measured according to Section 9.6. By requiring a value higher than 0.38, the standard provides an additional measure of safety over the previously widely-used ASTM C1028 wet SCOF value of 0.60 (per research at TCNA on 300 tile surfaces)<sup>6</sup>.

After a 15-year wait, Dr. Bönig's work, and the work that preceded and followed, has borne fruit, not only in Germany, but also in the United States and potentially in many tile consuming countries of the world.

## Notes

1. *TCNA Tile Initiative 2013*, Tile Council of North America; included in *2013 TCNA Handbook for Ceramic, Glass, and Stone Tile Installation*, and available separately from TCNA as a free download at [www.tcnatile.com](http://www.tcnatile.com).
2. *TCNA Tile Initiative 2012*, Tile Council of North America; included in *2012 TCNA Handbook for Ceramic, Glass, and Stone Tile Installation*, and available separately from TCNA as a free download at [www.tcnatile.com](http://www.tcnatile.com).
3. In the German Ramp test, developed by Skiba, Scheil, and Windhövel of the Bergische Universität Wuppertal, a trained evaluator, wearing standardized footwear, walks on a flooring sample evenly coated with oil. Starting with the ramp in a horizontal position, the evaluator increases the angle of the ramp until a slip occurs. The angle at which the slip occurred is used to express the degree of slip resistance per the table below.
4. In order to determine the force components from which the friction requirement can be calculated, multi-component force platforms ("force plates") were employed to measure forces perpendicular to the surface ( $F_z$ ) and tensile and pressure forces in both tangential axes ( $F_y$  and  $F_x$ ).
5. Dr. Bönig's work preceded the development of a standard for making in situ measurements, and he subsequently moved on to other areas of endeavor. He is recognized today as one of the world's leading designers of industrial fastener technology with over 20 patents to his credit. Further research by Sebald and others led to the development of standards for making field measurements (ANSI A137.1 and DIN 51131) allowing Bönig's research to be applied in all hard surface flooring applications.
6. While the 300 tiles chosen were selected to represent a wide spectrum of surfaces, no claim is made or offered that this represented the entire spectrum of available tile surfaces nor can any inference be made regarding any individual tile surface. ASTM C1028 SCOF measurements and DCOF measurements cannot be directly compared or correlated on a per-tile basis, as different sensors, test conditions, and measurement physics are employed.

Slip Resistance	Acceptance Angle
R9	From 6° to 10°
R10	From 10° to 19°
R11	From 19° to 27°
R12	From 27° to 35°
R13	Over 35°

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