Journal of the National Academy of Forensic Engineers®

http://www.nafe.org
ISSN: 2379-3252

Vol. XVI No. 2 December 1999

The History of the 0.50 SCOF

by Michael Kravitz, P.E., (NAFE 451S)

Introduction

As Professional Engineers, we go to court and testify on the slipperiness or non-slipperiness of walking surfaces in slip and fall cases where personal injuries occur. We testify that a surface with a Static Coefficient of Friction (SCOF) of 0.50 or greater is safe and a surface where the SCOF of less than 0.50 is unsafe. The Courts accept this number as the definitive number, and cash awards may either granted or denied based on it.

But where did 0.50 come from, and how was it established? This paper looks at the history of friction and the threshold number of 0.50.

How was the standard static coefficient of friction (SCOF) established as being 0.5 (five tenths)? Generally, in publications dealing with slip and fall, it was always stated or estimated or assumed that a value of the SCOF above 0.5 was relatively safe, a value below 0.5 SCOF was relatively slippery. The ASTM standards promulgate the methods of measuring the SCOF but do not explain how the 0.5 SCOF was decided upon. In court, on one particular slip and fall case, the writer was retained by the defendant's attorney. The plaintiff's expert measured the dynamic coefficient of friction (DCOF) and presented his case to the jury along with a demonstration of a meter that determined the DCOF. It occurred to the writer during this trial that he did not know how the threshold value of 0.50 for the SCOF was arrived at, and that juries might think that the 0.5 was just a number pulled out of thin air with no basis or origin. It would also be confusing to the jury to have one expert measure the SCOF and the other expert measure the DCOF. This paper will attempt to research and examine how the 0.5 SCOF merits its value.

History of SCOF From Various Sources

The writer searched the Internet for information on the Coefficient of Friction and the origins of the 0.50 threshold value but did not discover any meaningful papers or articles regarding the subject. The writer then contacted the Document Services at the Linda Hall Library, an independent research library of Science, Engineering and Technology, and requested a search on material containing information about the 0.50 coefficient of friction.[1] The following excerpts from various publications are from recent and older papers.

Michael Kravitz, P.E., 484 West 43rd St., Suite #32-S, New York, NY 10036-6333

1. Sydney V. James of the Underwriter's Laboratories (UL) read a paper before the 30th midyear meeting of the National Association of Insecticide and Disinfectant Manufactures, Chicago, June 13, 1944, entitled, "What Is A Safe Floor Finish?",[6] where he states the following: (Emphasis provided by writer).

> "In studying the subject, our first consideration was given to the mechanism of walking. We desired to develop an adequate appreciation of the mechanical problems involved so as to be able to set up a test method which would give us a reliable basis for determining the slipping resistance of floors both with and without finishes."
>
> "An approximate analysis of the operation of walking shows that a person starts by swinging his body forward, with, let us say, the weight on the left foot. He reaches forward with his right foot and sets it down on the floor surface ahead of him. The first contact may be the back edge of the heel, but very soon the shoe rocks forward and the sole comes in contact. **The leg forms an angle with the vertical** and the weight of the body is gradually transferred to the foot."
>
> "The body continues to move forward by virtue of the thrust from the left foot still in contact with the floor. The angle of the right leg with the vertical now decrease until, momentarily, it is taking the weight in a vertically downward direction. As the body moves on forward the right leg is inclined at a backward angle and provides the thrust for the next step. Meanwhile the left leg and foot swing forward and the action is repeated.
>
> "The essential point of this process, it seems to us, is that **the shoe is in stationary contact with the floor during the walking action.** There may be some difference of opinion as to this. It would be extremely interesting to see "slow-motion" moving pictures of the walking process. I think we should see clearly that the shoe, although it may rock or roll slightly during the step, is essentially in stationary contact with the floor. **If a person tries to take too long a step on a slippery floor, the leading foot may slip because, in attempting to transfer the weight to it, the angle of the leg is too great and the friction at the shoe contact will not keep the foot from slipping.** Similarly, letting the leg take too great an angle backward may also result in slipping. Think of a person walking on stilts. On a slippery floor short steps are necessary, while on a rough floor long strides become possible." .....
>
> "..... **Allowance must be made for incorrect floor preparation and incorrect application as well as improper maintenance practices.**

> "Summing up the matter, therefore, our method of answering the question "What is a safe floor finish?" is to compare the surface friction of the finish-coated floor with that of the untreated floor and then if the coefficient of friction of the treated or finished surface is no less than that of the untreated surface, the finish is regarded as being a safe finish."

This paper primarily explained that the James Machine emulated human walking and did not consider the value of the static coefficient of friction or how it was derived. Apparently Mr. James arrived at the value of 0.50 static coefficient of friction after testing various materials, using the James Machine and applying a safety factor for which he called **allowances**.

2. Alex Sacher, Ph.D, president of the UPI-Universal Petrochemicals Inc., a specialty (janitorial/maintenance) chemicals consulting, research and development, testing and marketing company, wrote a paper for the ASTM Standardization News, August 1993, titled, "Slip Resistance and the James Machine 0.5 Static Coefficient of Friction—Sine Qua Non".[2] This paper was based in part on a previous paper by Dr. Sacher titled, "Is the 0.5 Static Coefficient of Friction Value a Bench Mark or a Watershed?".[3] Dr. Sacher writes,

> "On Jan. 15, 1945 [Sidney V.] James submitted a recommendation to the Casualty Council of Underwriters Laboratories Inc., in which he informed them that "...the criterion for judgment as to acceptability for listing [of floor covering, floor finishing, etc., materials] has not heretofore been defined in [the usual] terms of a minimum performance specification, but in general, on a comparative basis... [and further, that] a study... of [laboratory] test results as well as the [field] experience record covering a period of several years... has disclosed the fact that a minimum safe value of coefficient of friction may now be established. With our testing machine it has been found that a value of 0.50 may be set as this minimum acceptable coefficient.
>
> "Materials which have been found by experience to provide adequate underfoot safety have shown coefficients of at least 0.50. Floors and floor finishes providing appreciably less than this coefficient are found to be definitely slippery and therefore to be considered as unsafe. ...."
>
> "It is recommended that in the future, our tests be conducted in accordance with our established standard method and that if the coefficient of friction as determined by our machine is found to be 0.50 or over, the product be recommended for listing as an acceptable anti slip material."

> "This internal memorandum is the first, the seminal, document to my knowledge I which the 0.5 static coefficient of friction is identified as a watershed value and equated with human locomotion safety. Significantly, it is based on a correlation of laboratory test data with extensive field experience — ....."

Dr. Sacher stated that, to his knowledge, the January 15, 1945 recommendation of the 0.50 value of the static coefficient of friction stated by Mr. James was the first equating the human gait with locomotion safety. Mr. James continued testing and publishing his findings.

In 1951, the Federal Trade Commission, with the help of the wax and floor polish industry, issued rules. The wax and floor polish industry could not use the terms "Slip Resistant", "Slip Retardant", "Anti-slip" or any similar terms unless the dynamic coefficient of friction was not less than 0.40 using the Sigler pendulum test, or the static coefficient of friction was not less than 0.50 using the James machine. In 1964, the ASTM accepted the James machine as the test for the static coefficient of friction, along with the preparation of test surfaces and the leather shoe. This method became the standard in 1969. In May 1970, the Chemical Specialties Manufactures Association adopted the ASTM D2047-69 test method to test floor polish, requiring that the static coefficient of friction be equal to or greater than 0.50. Dr. Sacher concluded, "that 0.50 is a valid standard and that Mr. James was correct when he settled on this figure even though we do not know exactly how he arrived at it."

3. From the symposium on Slips, Stumbles, and Falls: Pedestrian Footwear and Surfaces, held in Denver, Colorado on October 23, 1989, sponsored by ASTM Committee F13, B. Everett Gray, Editor.[4]

> "A static COF of 0.50 is considered by many as a threshold for safety of surfaces, without considering that this threshold is related to the test method, the angle of contact between the footwear and the tread surface and that this angle is controlled by stride."

> "These papers show that the 0.50 static COF criteria is a figure determined by the James Machine in accordance with the D2047 test method that may only be used as a guideline for "normal" level field conditions and does not represent either the maximum or minimum COF required for all non slip pedestrian traction situations."

Mr. Gray states that the 0.50 static coefficient of friction was established by Mr. Sidney V. James when he created the friction testing machine named for him, the James Machine. The ASTM D2047 procedure used for testing the static coefficient of friction with the James Machine accepts and establishes Mr. James' threshold of 0.50 for slip/non slip surfaces. Mr. Gray opines that the James Machine does not represent all non slip pedestrian situations.

4. From a paper entitled, "Measurement of the Slipperiness of Walkway Surfaces", by Percy A. Sigler, Martin N. Geib, and Thomas H. Boone, published as part of the Journal of Research of the National Bureau of Standards, U.S. Department of Commerce, National Bureau of Standards, Research Paper RP1879, Volume 40, May 1948[5]:

> "A survey of worn heels showed that maximum wear usually occurs at the outside border of the rear portion of the heel. The contour of this worn portion is generally in the form of a curve rather than a straight line.
>
> "Probable angles that heels of shoes make with a walkway surface at the first instant of contact were determined from the motion pictures and from the contour of worn heels. For 35 men's shoes, the angle of contact ranged from 11º to 32º, with an average value of 23º. For 16 women's shoes, including both high and low heels, the angle ranged from 12º to 32º, with an average value of 19º. For 38º worn heels, the maximum angle that tangents to the worn portion made with a horizontal plane ranged from 19º to 33º, with an average value of 26º.
>
> "According to the literature, the horizontal component of the force exerted by the leg on a walkway surface reaches a maximum in the forward direction shortly after the heel makes contact with the walkway, decreases rapidly at first and then slowly as the foot deploys, and rapidly reaches a maximum in the backward direction as the ball of the foot prepares to leave the walkway. These horizontal components are the forces that must be counteracted by friction in order to avoid slipping."

This paper describes the approximate angles of worn heels for men's and women's shoes. This is important because it determines the values of the angles at which the heel strikes the walking surface and, therefore, the angle of the stride.

5. In a report titled, "An Overview of Floor Slip-Resistance Research With annotated Bibliography" by Robert J. Brungraber, issued January 1976, Institute for Applied Technology, National Bureau of Standards, Washington, D.C., 20234,[7] Mr. Brungraber compiled a list of publications relating to the 0.50 SCOF and summarized them. Following are some of the publications that refer to the 0.50 COF.

"Measurement of Safe Walkway Surfaces", by C. F. Ekkebus and W. Killey, published in the Soap/Cosmetics/Chemical Specialties, February, 1973,[2] states the following:

"Good brief description of the mechanics and biology of walking.

"Review of the history of $\mu >= 0.5$ requirement. Theoretical justification, using anthropometry, of 0.5 as being a conservative but reasonable restriction on μ to provide slip resistant surfaces; based on leg lengths and stride lengths of a group of 16 people that were studied. They would have to execute an unnaturally long stride to slip on a 0.5 floor during normal walking.

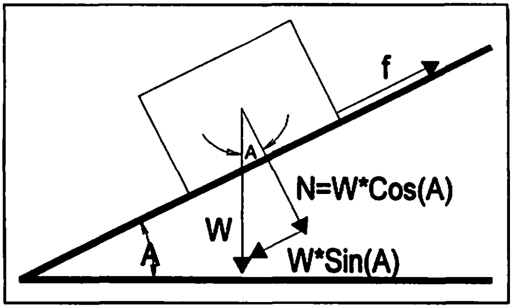
Discussion

The following is a review of the basics of friction. When the surface of one body comes into contact with the surface of another body, the reaction forces can be resolved into two components. One component is parallel to the contact surface and the other component is perpendicular to the contact surface. The component parallel to the contact surface is the frictional force. When there is no relative motion between the two bodies, the resistance to motion is called the static friction force. When the body moves relative to the contacting body the resistance force between the bodies is called the dynamic friction force. The frictional force between two bodies always opposes the relative motion between the two bodies. The static frictional force will increase as the force tending to cause sliding between the bodies increases. When the force tending to cause motion exceeds the friction force, motion occurs.

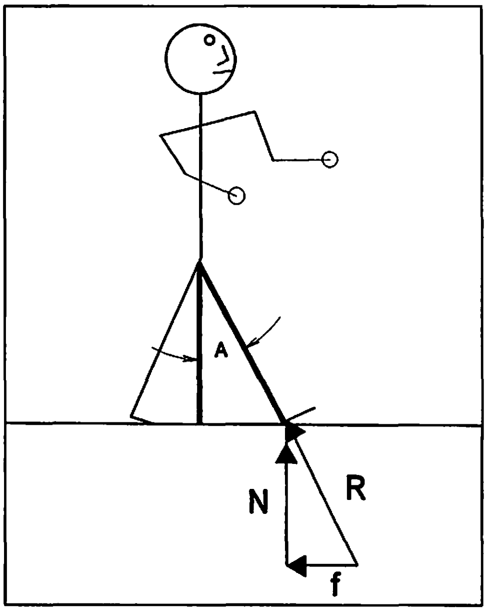
C. A. deCoulomb, in 1781, provided some of the earliest information on the laws of friction. A. J. Morin conducted experiments, and published them in 1831, confirming deCoulomb's results. Their work led to the following laws of friction for dry surfaces:[9]

1. The maximum frictional force which can be developed is proportional to the normal force.
2. The maximum frictional force which can be developed is independent of the size of the contact area.
3. The limiting static frictional force is greater than the kinetic frictional force.

If we look back at our physics class, when the instructor demonstrated the coefficient of friction, he put a block of wood on an inclined plane. When the block of wood began to slide down the plane, he measured the angle of the plane with the horizontal. By using a free body diagram it was proven that the



tangent of the angle of the slope with the horizontal plane was equal to the coefficient of friction. The adjacent figure demonstrates the inclined plane and a block mounted on the inclined plane. The figure is proportioned so that the vertical height is one-half the horizontal length. The resulting tangent of the angle of the inclined plane is one-half (0.5). The angle is approximately twenty-six and eight-tenths degrees (26.8°). Now let us rotate the angle of the inclined plane and place it on a datum. If we add a torso, a leg, and arms and a head to the rotated angle it represents the stick figure of a person walking. The writer took measurements of the angle from the hip to the heel of the forward foot with the vertical of normal walking persons. That angle measured approximately between eighteen degrees (18°) and twenty-two degrees (22°). The chart below indicates the tangent of the various angles and therefore the SCOF required to keep the forward heel from slipping forward or the rear sole from slipping backward. The chart indicates that, as the stride length increases, (an increasing angle), the higher the SCOF becomes to keep the heel or sole from slipping. Conversely, the shorter the stride, (a decreasing angle), the less the SCOF is necessary to keep the heel or sole from slipping. We know this from our own experience; for example, carefully walking around a tiled pool, or as one walks on ice and takes shorter steps. If the normal half stride is in the order of eighteen degrees (18°) to twenty-two degrees (22°) then we should be able to walk on surfaces with leather shoes with a SCOF of between three-tenths (0.30) to four-tenths (0.40) SCOF. However, by adding a safety factor to the three-tenths (0.30) to establish



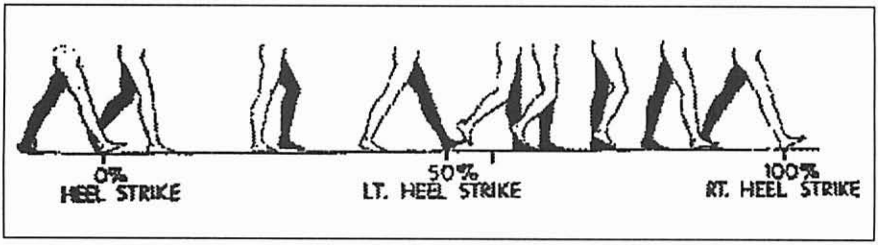
ANGLE	TAN (ANGLE)
30.6	0.59
28.6	0.55
26.6	0.50
24.6	0.46
22.6	0.42
20.6	0.38
18.6	0.34
16.6	0.30

five tenths (0.50), this results in sixty-seven percent (67%) increase, or a safety factor of 1.66, while adding a safety factor to four-tenths (0.40) to obtain five-tenths (0.50), results in a twenty-five percent (25%) increase, or a safety factor of 1.25.. Therefore the 0.50 SCOF value represents a safety factor of between approximately 25% to 67%, (1.25 to 1.66) for leather on a walkway surface. The safety factor would take into account various shoe material and also various conditions of the floor surface, i.e.; dirt, debris, residues, etc. This safety factor would include the "allowance" that Sidney James referred to in his 1944 paper discussed earlier.

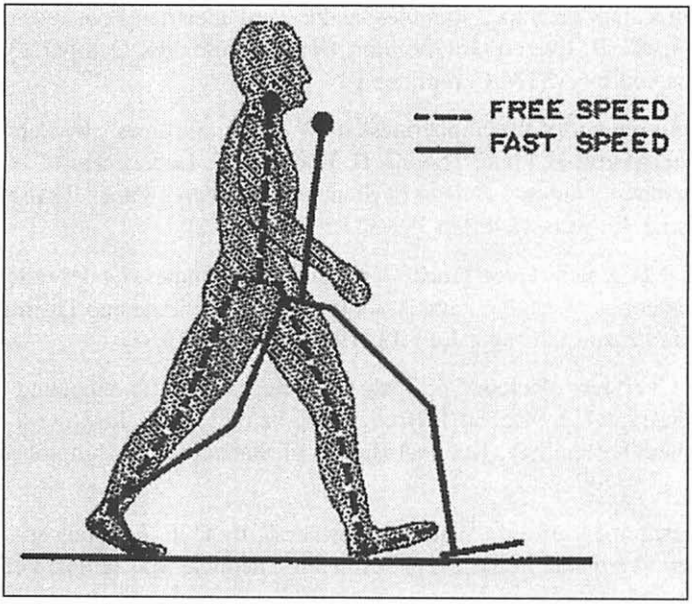
When a person walks normally, the forward heel comes into contact with the surface and has a relative motion with respect to the surface, or zero (0). This is similar to a tire patch in contact with the roadway or a tank tread (as seen in war movies) in contact with the ground. The friction force between the forward heel and the surface is opposite to the direction of travel, or toward the rear. When the sole of the rear foot pushes off, the friction force of the rear heel reverses direction toward the front. If the combination of the stride and surface is such that the heel of the forward foot creates a force greater than the friction force, then the forward foot will slip forward, causing the person to become unstable and probably fall either backwards or backwards and on the other foot. If the combination of the stride and surface is such that the sole of the rear foot creates a force greater than the friction force, then the rear sole will slip backward causing the person to become unstable and probably fall forward or on the knee.

Conclusion

The papers presented by Dr. Sacher in 1991 and 1993 and the paper by Sidney V. James show that we do not know exactly how Mr. James arrived at the 0.50 static coefficient of friction, only that he was probably correct in the evaluation based on his James Machine, the amount of testing he performed and his "allowance" factor. However, over the last forty (40) or fifty (50) years there have been many papers and experiments on the human gait and locomotion. Most scientists and engineers agree that the 0.50 value of the static coefficient of friction is valid for safe walking on level floors. Based on the human stride, the 0.50 SCOF represents a safety factor of approximately between 25% to 67% (1.25 to 1.66).



A graphic of the human gait.



A graphic of the human body at normal gait and fast gait.

References

1. Linda Hall Library, Document Services, 5109 Cherry Street, Kansas City, MO 64110-2498, (800) 662-1545, Home page http://www.lhl.lib.mo.us.
2. "Slip Resistance and the James Machine 0.5 Static Coefficient of Friction— Sine Qua Non", by Alex Sacher, Ph.D., ASTM Standardization News, August 1993, pp. 52-59.
3. "Is the 0.5 Static Coefficient of Friction Value a Bench Mark or a Watershed?", Alex Sacher, Ph.D., Ceramics Engineering Science Procedures, Volume 13, No. 1-2, pp. 29-45, 1992.
4. "Symposium on Slips, Stumbles, and Falls: Pedestrian Footwear and Surfaces", B. Everett Gray, Editor, Denver, Colorado, October 23, 1989, sponsored by ASTM Committee F13.
5. "Measurement of the Slipperiness of Walkway Surfaces", by Percy A. Sigler, Martin N. Geib, Thomas H. Boone, U.S. Department of Commerce, National Bureau of Standards, Research Paper RP1879, Volume 40, May 1948, pp.339-342.
6. "What Is A Safe Floor Finish?", by Sydney V. James, Underwriter's Laboratories (UL), National Association of Insecticide and Disinfectant Manufactures, Chicago, June 13, 1944, pp. 111-115.
7. "An Overview of Floor Slip-Resistance Research With annotated Bibliography" by Robert J. Brungraber, January 1976, Institute for Applied Technology, National Bureau of Standards, Washington, D.C., 20234.
8. "Measurement of Safe Walkway Surfaces", by C. F. Ekkebus and W. Killey, published in the Soap/Cosmetics/Chemical Specialties, February, 1973.
9. Engineering Mechanics, 2nd Edition, by Archie Higdon and William B. Stiles, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, Civil Engineering and Engineering Mechanics Series, N. M. Newmark, Editor, 1961, pp. 169 - 170.