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**Further Slip-Resistance Testing Of Footwear For
Use At Work**

**Report Number
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CONTENTS

1	Introduction	1
2	Experimental	3
2.1	Surface Roughness Testing	3
2.2	Pendulum Testing.....	4
2.3	Ramp Testing	5
2.4	Sole Hardness Testing.....	7
3	Results and Discussion.....	8
3.1	Surface Roughness Testing	9
3.2	Pendulum Testing.....	9
3.3	Ramp Testing	10
3.4	Sole Construction And Materials Testing	21
4	Conclusions	27
5	Future Work	29
6	References	31
	Appendix 1	32
A1.1	Interpretation of Surface Roughness Results using UKSRG Guidelines	32
A1.2	Interpretation of Pendulum Results using UKSRG Guidelines	32
A1.3	Interpretation of Ramp Results using UKSRG Guidelines	32
A1.4	Reliability of Four-S / Slider 96 Pendulum and Ramp Test Results	32
	Appendix 2	33
A2.1	Estimation of Experimental Errors in Ramp Testing	33
A2.2	Steel and Water Results.....	34
A2.3	Steel and Glycerol Results	34
A2.4	Quarry and Glycerol Results.....	35
A2.5	Chequer Plate and Water Results	36
A2.6	Chequer Plate and Glycerol Results.....	36

EXECUTIVE SUMMARY

Previous work carried out by HSL (Report PED/05/04), investigated the slip resistance of occupational footwear. For the purposes of this report 'occupational footwear' includes any footwear intended for use at work. The aim of the current study was to expand this work to assess the slip resistance of a wider range of occupational footwear. It is intended that the results generated in the course of this work should form the basis of an information table to aid HSE and local authority inspectors in providing advice on appropriate footwear to duty holders.

A further 28 pairs of occupational footwear were assessed for slip resistance using the standard HSL-PS-SOP12 ramp test, also known as the UKSRG Ramp Test (HSE, 2007) on steel with water contamination. Shoes that were shown to pose a moderate or low slip potential on wet steel were subjected to additional testing.

Testing identified 11 pieces of footwear which pose a low slip potential on wet steel and 23 pieces of footwear which posed a moderate slip potential on wet steel. A further 18 types of footwear were classified as a high slip potential on wet steel. On glycerol contaminated steel the slip resistance results were much lower, with only one pair achieving a moderate slip potential.

All the shoes used in the previous study were shown to pose a low slip potential on a water wet quarry tiled surface, so no further testing was done under these conditions. This study has identified 7 shoes which present a low slip potential on quarry tile contaminated with glycerol.

Further testing was then carried out on aluminium chequer plate under water and glycerol contaminated conditions. Ramp tests were carried out in the direction found to offer the least slip resistance by the pendulum test, i.e. under the most demanding conditions. Although limited, the results suggest that chequer plate surfaces do not always provide an improved slip resistance over un-profiled sheet steel in water-wet conditions. It does however appear that the profiled surface is advantageous when compared to sheet steel for glycerol contamination in the majority of cases.

The data generated demonstrates that understanding the slip resistance properties of footwear is complex and is likely to be dependent upon several variables. Soling material, cleating pattern, microroughness and hardness may all play an important role. Footwear manufacturers may be

able to improve the slip resistance of their product simply by using softer compounds for the soling materials.

The ramp testing suggests that there is an increasing number of shoes available in the marketplace that provide a good level of slip resistance in water contaminated conditions even on highly demanding surfaces such as sheet steel. The study also highlighted the comparative lack of shoes that perform well with more viscous contaminants such as glycerol.

It should be noted that the shoes tested here were in new condition. The slip resistance of a shoe can change dramatically with wear (Kim *et al*, 2001). Although the sample preparation procedure involves abrading the sole surface with P400 grade sandpaper, which represents relatively little wear when compared to the expected life of the shoe, it was noticed that the slip resistance of some footwear changed during testing. The results presented here will give an indication of slip resistance of a new shoe, but may not give a true representation of the performance of a shoe after a moderate period of use. This is an important issue when using the information presented here as an aid to select footwear, and is consistent with earlier recommendations that field trials are the best way to assess the suitability of footwear to any given environment. Procurers of footwear should not select footwear on the basis of laboratory test results alone. Also, footwear selection has to take account of a number of other factors, such as comfort, durability and any additional safety features required, such as steel mid-sole. The final choice may have to be a compromise.

1 INTRODUCTION

The work detailed in this report was carried out at the request of Mr. John Worth (Safety Unit, HSE).

Previous work carried out by HSL (Report PED/05/04), investigated the slip resistance of a number of types of safety, protective and occupational footwear. The term 'occupational footwear' used in this report is applied to any footwear intended for use at work. The aim of the current study was to further assess the slip resistance of a wider range of occupational footwear. It is intended that the results generated in the course of this work should form the basis of an information table to aid inspectors in providing advice on appropriate footwear to duty holders. A further 27 pairs of occupational footwear were tested, and of the original 27, 3 have been removed as they are no longer available. Also included in this study were Four-S shoes, designed as a laboratory control test, giving a total of 52 pairs of footwear, 51 of which are for inclusion in the information to aid inspectors.

Choosing the most suitable slip-resistant footwear for a particular environment/ work activity can be problematic. Descriptions of slip resistance given in supplier's brochures include terminology ranging from 'improving the grip performance' to 'excellent multi-directional slip-resistance'. Often, the brochures do not describe the work environments for which the footwear are, or are not, suitable.

Slip-resistant industrial footwear will normally have been tested for slip resistance according to BS EN 13287:2004 - Personal protective equipment - footwear - test method for slip resistance. Footwear tested in the original study were also tested to BS EN 13287. It is suggested that the slipperiness thresholds which determine whether footwear passes the test need to be raised to make the test more challenging, but this will take time. Reliable information on the slip resistance performance of specific flooring / footwear / contamination combinations can also be obtained using the DIN ramp coefficient of friction test. A version of this test method has been developed by HSL, known as HSL-PS-SOP12, to complement the method described in BS EN 13287.

All the footwear studied was assessed using the standard HSL-PS-SOP12 ramp test on steel with water contamination. Footwear that was identified as presenting a low or moderate slip potential on wet steel, along with footwear which was identified as a high slip potential on wet steel but made claims of slip resistance, were subjected to further testing on steel and quarry tile surfaces with glycerol contamination. Glycerol is a much more viscous contaminant than water, and so it is

harder for the footwear to break through a squeeze film and grip the walking surface (Lemon & Griffiths, 1997). Footwear identified as posing a low slip potential on steel were also evaluated on aluminium chequer plate with both water and glycerol contamination.

The majority of the footwear tested was identified from marketing and promotional literature and was selected to give a cross section of the occupational footwear available irrespective of claims of slip resistance. Some of the footwear was selected at the suggestion of a duty holder or inspector as footwear which had been used, successfully or unsuccessfully, in workplace environments as an anti slip control. All of the shoes used in the current trial had to meet the following criteria:

1. They are manufactured and marketed specifically as occupational footwear.
2. They are widely and easily available to duty holders.

Supplier details are not given as part of this report as most of the footwear used in the study is available from a range of outlets.

14 of the 27 examples of occupational footwear tested in the original study were specifically marketed as slip resistant or referred to as having anti-slip soles, although these claims did not always appear to be justified. Of the 10 shoes identified as a high slip potential on water contaminated steel, 5 (50%) were marketed as slip resistant. This investigation looks at this aspect further to see if claims of slip resistance have changed in terms of prevalence or accuracy.

2 EXPERIMENTAL

Slip resistance data for each of the ramp boards used in the current work were generated in accordance with the guidelines recommended by the United Kingdom Slip Resistance Group (UKSRG) Issue 3 (2005). Two slip resistance test methods were employed as outlined in the UKSRG Guidelines, a Surtronic Duo microroughness transducer (see Fig. 2.1), and a ‘Stanley’ Pendulum Coefficient of Dynamic Friction (CoF) Test (see Fig. 2.2). Both test methods are used routinely by HSL during on-site slipperiness assessments, as well as for contract research for HSE.

2.1 SURFACE ROUGHNESS TESTING

The Surtronic was calibrated against a UKAS roughness standard and checked in-situ using a calibrated roughness plate. Interpretation of surface roughness data are based on HSE Guidance “Assessing the slip resistance of flooring – a technical information sheet. Slips and Trips 1 revised.” and the UKSRG Guidelines (Appendix 1.1).



Fig 2.1. The Surtronic Duo microroughness transducer

The Rz roughness was measured in 4 different directions to check for any directionality in the materials. The average of 10 measurements is reported.

2.2 PENDULUM TESTING

A single type of pendulum test slider was used; Slider-96, also known as 'Four-S' rubber (Standard Simulated Shoe Sole). This material was developed by the UKSRG in collaboration with RAPRA Technology Ltd. as a standard material for the assessment floor surface slip resistance. This material was developed to represent a shoe soling material of moderate slip resistance. Slider preparation was carried out as per the UKSRG Guidelines. The Pendulum is calibrated by the British Standards Institution at 12 month intervals. Interpretations of pendulum data are based on the UKSRG Guidelines, 2005 (Appendix 1.2).



Fig 2.2. The 'Stanley' Pendulum CoF test

Pendulum tests were carried out in 3 directions to check for any directionality in the materials, in both dry and water wet conditions. Each test consists of 8 swings, 3 for conditioning and then the 5 test values. The average of the five test values is calculated and reported.

2.3 RAMP TESTING

Reliable information on the slip resistance of specific flooring / footwear combinations can be obtained using the ramp based coefficient of friction test. A version of this test method has been developed by the Health & Safety Laboratory (HSL), HSL-PS-SOP12, also known as the UKSRG Ramp Test (HSE, 2007) see Figure 2.3.



Fig 2.3. The 'HSL-PS-SOP12' ramp-type CoF test.

Two different contaminants were used on the ramp during the work presented. The first used potable water at a flow rate of approximately 6 l/min and the second used glycerol, 100 ml of which was applied to the floor at the beginning of each test. These volumes are designed to achieve saturation of the surface and maintain this level of contamination throughout the test.

Three test surfaces were selected for these trials:

- Steel sheet - a surface which offers very little in the way of surface roughness. Shoes which were classified as a moderate or low slip potential on wet steel were then tested on glycerol contaminated steel.

- Aluminium chequer plate - a common profiled metal flooring which is generally perceived as being highly slip resistant. Only shoes which were classified as a low slip potential on wet steel were tested on chequer plate with both water and glycerol.
- Quarry tile - a rougher tiled surface which should provide an increased level of grip over the steel. Shoes which were classified as a moderate or low slip potential on wet steel, along with footwear which were identified as a high slip potential on wet steel but made claims of slip resistance, were tested on glycerol contaminated quarry tile. All shoes previously tested were shown to pose a low slip potential on wet quarry tiles, so only testing with glycerol contamination was carried out.

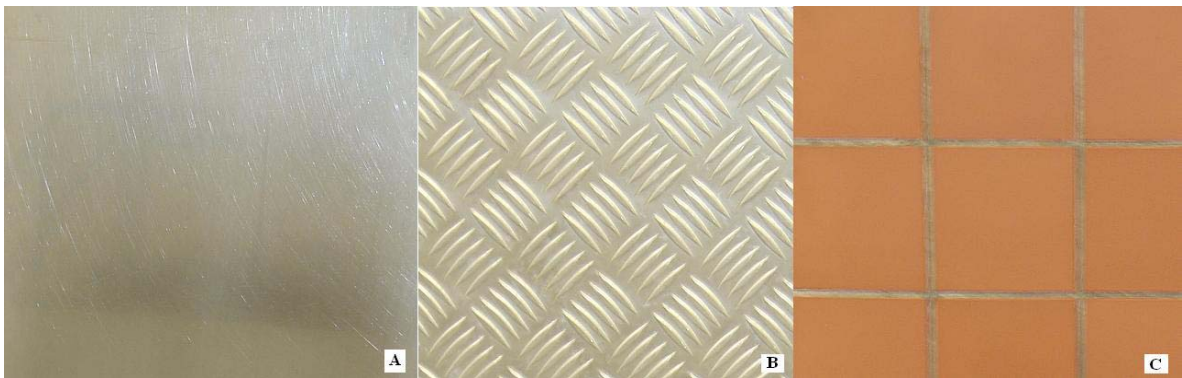


Fig 2.4. The test surfaces; Steel (A), Aluminium chequer plate (B) and Quarry tile (C).

The ramp tests were conducted according to HSL-PS-SOP12. Starting from the level, the operator increased the inclination of the ramp in approximately 1° increments until an unrecoverable slip was initiated and the angle of the ramp was recorded. Twelve angles were determined, with the highest and lowest values being discarded. The 10 remaining values were then averaged to give the critical angle. The coefficient of friction for level walking was then determined by taking the tangent of the critical angle. The results presented here were generated by two operators who achieved mean angles within 2° of each other. Interpretations of ramp data are adapted from the UKSRG Guidelines (Appendix 1.3).

An analysis of the potential experimental errors arising from this test methodology is given in Appendix 2.

2.4 SOLE HARDNESS TESTING

Hardness measurements were taken from the soles of the footwear tested. The Durotech Shore hardness meter is shown in Figure 2.5.



Fig 2.5 The Durotech M202 Shore hardness meter.

Nine measurements were taken from different areas of the sole area, 4 from the heel and 5 from the forepart. Where more than one material has been used the measurements were taken from the most prevalent material.

3 RESULTS AND DISCUSSION

All results are interpreted in accordance with the current UKSRG guidelines (Issue 3, 2005) for classification as a high, moderate or low potential for pedestrian slip. Throughout this report these will be colour coded red, amber and green respectively. The relevant tables from the UKSRG guidelines are reproduced in Appendix 1.

3.1 SURFACE ROUGHNESS TESTING

Surface roughness results for the ramp boards used in this work are given in Table 3.1.

Ramp Board	Average Rz Surface Roughness (μm)
Steel	1.5
Aluminium Chequer Plate	2.9
Quarry Tile	17.4

Table 3.1. Table giving average R_z surface roughness (μm) results for the three ramp boards

3.2 PENDULUM TESTING

Pendulum Test Value (PTV) results for the ramp boards used in this study are given in Table 3.2.

Ramp Board	Direction	Dry (PTV)	Wet (PTV)	Slip Potential in Wet
Steel	Direction I	66	10	High
	Direction II	57	9	High
	Direction III	58	9	High
Chequer plate	Direction I	64	19	High
	Direction II	61	26	Moderate
	Direction III	69	30	Moderate
Quarry Tile	Direction I	63	38	Low
	Direction II	63	44	Low
	Direction III	62	42	Low

Table 3.2. Table giving 4S pendulum results in dry and wet conditions for each of the ramp boards

The surface roughness data suggests that the steel board would be expected to pose a high slip potential in wet conditions. This was confirmed by the Four-S pendulum data, which showed the steel board to have a low slip potential in dry conditions and a high slip potential when wet.

The surface roughness data for the chequer plate board indicates it should pose a high slip potential when wet. Four-S pendulum results show the chequer plate board to be a low slip potential when dry and a moderate to high slip potential in water wet conditions. The range of the pendulum results illustrates the effect of the directionality of the chequer plate pattern.

The surface roughness data suggests that the quarry board should pose a moderate slip potential in wet conditions. Four-S pendulum results show the quarry board to be a low slip potential when dry and low slip potential in water wet conditions.

3.3 RAMP TESTING

3.3.1 STEEL AND WATER RAMP TESTING

28 new pairs of occupational footwear were tested according to HSL-PS-SOP12 using potable water as a contaminant on sheet stainless steel. The steel floor used in this initial phase of ramp testing was deliberately selected to be a severe test of the footwear, but it does represent a reasonable approximation of the worst-case scenario likely to be found in many real workplaces with smooth, hard floors. Footwear that is identified as performing well in this test may therefore be reasonably expected to perform well under water-contaminated conditions in the workplace. The ramp results are given in Table 3.3 with the shoes ranked from the most slip resistant to the least. These results are also presented graphically in Appendix 2.

Shoe	Shoe Type	Marketed As Slip Resistant	Steel / Water CoF
Shoes For Crews (8092, 8096)	Dress shoe, Boot, Trainer, Wellington. Toe protection available	Yes	0.52
Hyper V Sole - Spidermax Black	♣Trainer and Wellington. Toe protection	Yes	0.51
Keuka Café Softer Soles	♣Shoe, Boot, Trainer. Toe protection	Yes	0.41
Slip Grips – Spider Grip sole (5332)	Shoe, Boot, Slip-on. Toe protection	Yes	0.41
Inyati Wellington (127)	♣Wellington. Toe protection	Yes	0.39
TredSafe (Chef)	♣Slip-on shoe. Other styles are available.	Yes	0.38
Dunlop Purofort – High Grip	Wellington. Toe protection	Yes	0.38
V6 Powerwear (V6000)	♣Safety Boot/ Toe / Mid-sole protection.	No	0.37
Goliath Atomium (Atom63)	♣Slip-on ankle boot, Slip-on shoe, Trainer. Toe protection	Yes	0.37
Bata Industrials (Thor 705-69911)	♣Safety Boot/ Toe / Mid-sole protection.	No	0.37
Uvex Classic (8451.9) – Ultra Grip sole	Safety Boot/shoe. Toe protection. Midsole protection available.	No	0.36
Schurr A (1133301)	Shoe.	Yes	0.35
Aimont Safety Shoe (774400)	Shoe. Toe protection	No	0.35
Bata Safemaster	Wellington. Toe / Midsole protection	Yes	0.34
Emma Venus	Shoe. Toe protection	No	0.34
ABS (ABS220P)	Shoe, Boot. Toe protection available	Yes	0.33
Keuka Café Overshoe	♣Overshoe	Yes	0.33
Tuskers 632 Unisex Safety Shoe	♣Shoe, slip-on. Toe protection	Yes	0.33
Centek (FS140)	Rigger Boot. Toe / Midsole protection	No	0.32
Uvex Quattro – (8411.2)	Safety Boot/shoe. Toe / Midsole protection	No	0.32
Otter 93609	♣Shoe. Toe protection	No	0.32
Globe Trotter Rigger Boot	♣Rigger Boot. Toe / Midsole protection	No	0.32
Arco Sandyderm – Cofra Aderplus sole (6641)	Slip-on shoe. Toe protection. Other styles are available.	Yes	0.31
Cofra Minorca Safety Shoe Cofra Wave Sole	♣Shoe, Boot, Trainer, Slip-on. Toe / Mid-sole protection	Yes	0.30
Otter 98402	♣Shoe. Toe protection	No	0.30
Tuf (P5600)	Office Shoe. Toe protection	No	0.29
Footsure Mudguard Gibson (FS65)	Office Shoe. Toe protection	No	0.29
Jalas Tandem Sport Geox (5910)	Office Shoe	No	0.29

Shoe	Shoe Type	Marketed As Slip Resistant	Steel / Water CoF
Tuskers Aquagrip Boot 388	♣Office Shoe, Dress Boot, Boot. Available with Toe / Mid-sole protection	Yes	0.28
Sievi Solid XL+	♣Boot. Toe / Midsole protection	No	0.28
Dunlop Purofort Rig Air	♣Rigger Boot. Toe / Midsole protection	No	0.28
Jallatte Jaldonnel SAS Boot. Tritane sole	♣Shoe, Boot, Trainer. Toe / Mid-sole protection	No	0.27
Gaston Mille Louisiana Clean Sole	♣Boot. Toe / Midsole protection	No	0.27
Arco Boot - Cofra Supergrip "Flag sole" (F88)	Boot. Available with Toe / Midsole protection	Yes	0.26
Inyati Clog	♣Slip on clog. Toe protection	No	0.25
Panther Dakota (21094 14 S3)	Safety Boot. Toe protection	No	0.25
Bata Hazmax (892-77210K)	Wellington. Toe / Midsole protection	Yes	0.25
Arco Basics Wellington	♣Wellington	No	0.25
Cofra Stanton Off-Road Sole Safety Boot	♣Shoe, Boot, Rigger Boot. Toe / Mid-sole protection	No	0.23
Heckel MC Silver Boot (Z12300)	Boot. Toe / Midsole protection	No	0.23
Bacou Bac run 783 safety Boot	♣Boot. Toe / Midsole protection	No	0.23
Ruff Lander (S17)	Boot. Toe protection	No	0.23
Ruff Lander (S64)	Rigger Boot. Toe / Midsole protection	No	0.20
Ergoli / Inyati CB4 Boots	♣Ankle Wellington. Toe protection	No	0.20
Precision Wheat Ankle Boot (8801)	Boot. Toe protection	Yes	0.18
Dr. Martens Grip Trax	Boot. Toe protection	Yes	0.18
Magnum Patrol	♣Boot. Available with Toe / Midsole protection	No	0.18
Precision Black Trainer (5500)	♣Trainer. Toe protection	Yes	0.17
Quiva (Quiva 06/A)	♣Medical Clogs	Yes	0.15
Dr. Martens Tred safety Chukka Boot (6G8100)	♣Safety Boot. Toe protection	Yes	0.15
Trojan Elite H64 Black Safety Shoe	♣Shoe. Toe / Mid-sole protection	No	0.13
Four-S Shoe	Standard shoe sole	No	0.07

Table 3.3. Ramp results for all the shoes on steel with water contamination. Shoes presenting a high slip potential are shown in red, shoes posing a moderate slip potential are shown in orange and a low slip potential is shown in green. Additional information on shoe type is given in column 2. Shoes which are marketed with claims of slip resistance are identified in column 3. ♣ = new since last report

Testing has identified a total of 11 (of which 7 are new for this study) pieces of footwear which pose a low slip potential on wet steel. A total of 23 (of which 10 are new) pieces of footwear were identified as posing a moderate slip potential on wet steel. The remaining 18 types of footwear were classified as a high slip potential on wet steel.

Pendulum tests have shown the steel board to be a high slip potential in wet conditions as the available surface roughness is insufficient to break through the squeeze film formed (Lemon & Griffiths, 1997). Shoes that pose a moderate or low slip potential on wet steel demonstrate average or better slip resistance, and are worth further study.

Table 3.3 also highlights how marketing claims of slip resistance of footwear relates to actual performance as determined by HSL-PS-SOP12. A total of 52 types of footwear were tested, of

which 24 (46%) were marked as slip resistant. Of the 18 shoes that were rated as a high slip potential on wet steel, 6 (33%) were marketed as slip resistant. Conversely, of the 11 shoes rated as a low slip potential on wet steel, 3 (25%) were not marketed as slip resistant.

This further illustrates that some claims of slip resistance are apparently being made regardless of slip performance, and that although this claim may be justified in some cases (8 out of top 10 scores on wet steel set by “slip resistant” shoes) this is not always the case (5 out of bottom 10 scores on wet steel set by “slip resistant” shoes). What is unclear is whether these inconsistencies are due to limitations in the footwear testing methodologies or to the thresholds for passing the tests being too low, but it does suggest that information provided by manufacturers may not always be sufficient to enable the best choice to be made. This gives an indication of how difficult it can be for duty holders to identify footwear with good slip resistant properties based solely on manufacturers’ claims.

3.3.2 STEEL AND GLYCEROL RAMP TESTING

Footwear that posed a moderate or low slip potential on wet steel was subjected to additional testing. The ramp tests on steel were repeated with glycerol contamination. Glycerol was chosen to be representative of more viscous contaminants such as gravy and sauces used in the food industry and of lubricating oils in manufacturing. The results are given in Table 3.4 with the shoes ranked from the most slip resistant on wet steel to the least, to allow easy comparison to previous results. These results are also presented graphically in Appendix 2.

The aim of these tests was to identify footwear that performed well with more viscous contaminants, as such contamination is common in real workplace situations such as kitchens, machine shops and factories. The ramp tests have again highlighted a lack of footwear with good slip resistance in the presence of viscous contaminants currently available in the marketplace, albeit on a challenging test surface such as steel.

Tests showed that none of the shoes in the study pose a low slip potential for steel contaminated with glycerol, and only one pair of shoes (Shoe for Crews) presented a moderate slip potential. All the other shoes tested pose a high slip potential on steel with glycerol contamination. This confirms the findings of the previous work (Report PED/05/04) where the same result was found.

The increased viscosity of the glycerol contamination compared to water dramatically reduced the coefficient of friction achieved by any given pair of shoes. This finding is in line with previous research on squeeze film thickness and footwear conducted by HSL for HSE (Lemon & Griffiths, 1997).

Shoe	Shoe Type	Steel / Water CoF	Steel / Glycerol CoF
Shoes For Crews (8092, 8096)	Dress shoe, Boot, Trainer, Wellington. Toe protection available	0.52	0.31
Hyper V Sole - Spidermax Black	♣Trainer and Wellington. Toe protection	0.51	0.18
Keuka Café Softer Soles	♣Shoe, Boot, Trainer. Toe protection	0.41	0.24
Slip Grips – Spider Grip sole (5332)	Shoe, Boot, Slip-on. Toe protection	0.41	0.17
Inyati Green Wellington (127)	♣Wellington. Toe protection	0.39	0.11
TredSafe (Chef)	♣Slip-on shoe. Other styles are available.	0.38	0.18
Dunlop Purofort – High Grip	Wellington. Toe protection	0.38	0.15
V6 Powerwear (V6000)	♣Safety Boot/ Toe / Mid-sole protection.	0.37	0.10
Goliath Atomium (Atom63)	♣Slip-on ankle boot, Slip-on shoe, Trainer. Toe protection	0.37	0.14
Bata Industrials (Thor 705-69911)	♣Safety Boot/ Toe / Mid-sole protection.	0.37	0.12
Uvex Classic (8451.9) – Ultra Grip sole	Safety Boot/shoe. Toe protection. Midsole protection available.	0.36	0.05
Schurr A (1133301)	Shoe.	0.35	0.06
Aimont Safety Shoe (774400)	Shoe. Toe protection	0.35	0.13
Bata Safemaster	Wellington. Toe / Midsole protection	0.34	0.05
Emma Venus	Shoe. Toe protection	0.34	0.15
ABS (ABS220P)	Shoe, Boot. Toe protection available	0.33	0.16
Keuka Café Overshoe	♣Overshoe	0.33	0.17
Tuskers 632 Unisex Safety Shoe	♣Shoe, slip-on. Toe protection	0.33	0.20
Centek (FS140)	Rigger Boot. Toe / Midsole protection	0.32	0.09
Uvex Quattro – (8411.2)	Safety Boot/shoe. Toe protection. Midsole protection available.	0.32	0.09
Otter 93609	♣Shoe. Toe protection	0.32	0.12
Globe Trotter Rigger Boot	♣Rigger Boot. Toe / Midsole protection	0.32	0.08
Arco Sandyderm – Cofra Aderplus sole (6641)	Slip-on shoe. Toe protection. Other styles are available.	0.31	0.11
Cofra Minorca Safety Shoe Cofra Wave Sole	♣Shoe, Boot, Trainer, Slip-on. Toe / Mid-sole protection	0.30	0.14
Otter 98402	♣Shoe. Toe protection	0.30	0.09
Tuf P5600	Office Shoe. Toe protection	0.29	0.10
Footsure Mudguard Gibson (FS65)	Office Shoe. Toe protection	0.29	0.16
Jalas Tandem Sport Geox (5910)	Office Shoe	0.29	0.13
Tuskers Aquagrip Boot 388	♣Office Shoe, Dress Boot, Boot. Available with Toe / Mid-sole protection	0.28	0.15
Sievi Solid XL+	♣Boot. Toe / Midsole protection	0.28	0.13
Dunlop Purofort Rig Air	♣Rigger Boot. Toe / Midsole protection	0.28	0.05
Jallatte Jaldonnel SAS Boot. Tritane sole	♣Shoe, Boot, Trainer. Toe / Mid-sole protection	0.27	0.08
Gaston Mille Louisiana Clean Sole	♣Boot. Toe / Midsole protection	0.27	0.15
Arco Boot - Cofra Supergrip “Flag sole” (F88)	Boot. Available with Toe / Midsole protection	0.26	0.13
Four-S Shoe	Standard shoe sole	0.07	0.01

Table 3.4. Ramp test results for steel with water and glycerol contamination. Shoes presenting a high slip potential are shown in red, shoes posing a moderate slip potential are shown in orange and a low slip potential are shown in green. ♣ = new since last report

3.3.3 QUARRY TILE RAMP TESTING

Footwear that presented a moderate or low slip potential on wet steel, along with footwear which was identified as a high slip potential on wet steel but made claims of slip resistance, were subjected to additional testing on quarry tiles with glycerol contamination. This surface was selected to be representative of the type of floor commonly found in real workplace environments.

All the shoes previously tested were shown to present a low slip potential on wet quarry tiles. This is in line with the pendulum results, which showed the quarry tiles to be a low slip potential in the water-wet condition. Therefore we can assume that the results will be as previously reported, so tests on quarry tile with water contamination were not carried out with the new test shoes.

The previous ramp tests showed that two of the shoes studied posed a low slip potential on glycerol contaminated quarry tiles (Shoes for Crews and Slip Grips) and five pairs of shoes posed a moderate slip potential. All the remaining shoes tested were shown to pose a high slip potential.

Ramp testing of the new footwear on glycerol contaminated quarry tiles indicates:

- 7 shoes pose a low slip potential (increased from 2)
- 9 shoes pose a moderate slip potential (increased from 5)

The shoes that achieved a low slip potential classification on quarry tiles contaminated with glycerol are listed alphabetically below:

Inyati Wellington (127)
Keuka Café
Keuka Café Overshoe
Shoes For Crews (8092, 8096)
Slip Grips – Spider Grip sole (5332)
TredSafe (Chef)
Tuskers 632 Unisex Safety Shoe

The results are given in Table 3.5 with the shoes ranked from the most slip resistant on wet steel to the least. These results are also presented graphically in Appendix 2.

Shoe	Shoe Type	Quarry / Glycerol CoF
Shoes For Crews (8092, 8096)	Dress shoe, Boot, Trainer, Wellington. Toe protection available	0.40
Hyper V Sole Spider Max Black	♣Trainer and Wellington. Toe protection	0.34
Keuka Café Softer Soles	♣Shoe, Boot, Trainer. Toe protection	0.50
Slip Grips – Spider Grip sole (5332)	Shoe, Boot, Slip-on. Toe protection	0.39
Inyati Wellington (127)	♣Wellington. Toe protection	0.38
TredSafe (Chef)	♣Slip-on shoe. Other styles are available.	0.55
Dunlop Purofort – High Grip	Wellington. Toe protection	0.27
V6 Powerwear (V6000)	♣Safety Boot/ Toe / Mid-sole protection.	0.18
Goliath Atomium (Atom63)	♣Slip-on ankle boot, slip-on shoe, trainer. Toe protection	0.32
Bata Industrials (Thor 705-69911)	♣Safety Boot/ Toe / Mid-sole protection.	0.20
Uvex Classic (8451.9) – Ultra Grip sole	Safety Boot. Toe protection	0.20
Schurr A (1133301)	Shoe.	0.17
Aimont Safety Shoe (774400)	Shoe. Toe protection	0.20
Bata Safemaster	Wellington. Toe / Midsole protection	0.20
Emma Venus	Shoe. Toe protection	0.26
ABS (ABS220P)	Shoe, Boot. Toe protection available	0.34
Keuka Café Overshoe	♣Overshoe	0.36
Tuskers 632 Unisex Safety Shoe	♣Shoe, slip-on. Toe protection	0.39
Centek (FS140)	Rigger Boot. Toe / Midsole protection	0.22
Uvex Quattro – (8411.2)	Safety Boot. Toe / Midsole protection	0.17
Otter 93609	♣Shoe. Toe protection	0.17
Globe Trotter Rigger Boot, Contract Range	♣Rigger Boot. Toe / Midsole protection	0.21
Arco Sandyderm – Cofra Aderplus sole (6641)	Slip-on shoe. Toe protection. Other styles are available.	0.30
Cofra Minorca Safety Shoe Cofra Wave Sole	♣Shoe, Boot, Trainer, Slip-on. Toe / Mid-sole protection	0.24
Otter 98402	♣Shoe. Toe protection	0.16
Tuf (P5600)	Office Shoe. Toe protection	0.20
Footsure Mudguard Gibson (FS65)	Office Shoe. Toe protection	0.18
Jalas Tandem Sport Geox (5910)	Office Shoe	0.21
Tuskers Aquagrip Boot 388	♣Office Shoe, Dress Boot, Boot. Available with Toe / Mid-sole protection	0.30
Sievi Solid XL+	♣Boot. Toe / Midsole protection	0.32
Dunlop Purofort Rig Air	♣Rigger Boot. Toe / Midsole protection	0.19
Jallatte Jaldonnel SAS Boot Triftane sole	♣Shoe, Boot, Trainer. Toe / Mid-sole protection	0.23
Gaston Mille Louisiana Clean Sole	♣Boot. Toe / Midsole protection	0.20
Arco Boot - Cofra Supergrip “Flag sole” (F88)	Boot. Available with Toe / Midsole protection	0.26
Inyati Clog	♣Slip on clog. Toe protection	0.17
Quiva (Quiva 06/A)	♣Medical Clogs	0.11
Bata Hazmax (892-77210K)	Wellington. Toe / Misdoles protection	0.12
Precision Wheat Ankle Boot (8801)	Boot. Toe protection	0.14
Dr. Martens Grip Trax	Boot. Toe protection	0.09
Precision Black Trainer (5500)	♣Trainer. Toe protection	0.09
Quiva (Quiva 06/A)	♣Medical Clogs	0.10
Dr. Martens Tred safety Chukka Boot (6G8100)	♣Safety Boot. Toe protection	0.11

Table 3.5. Ramp test results for quarry tile with glycerol contamination. Shoes presenting a high slip potential are shown in red, shoes posing a moderate slip potential are shown in orange and a low slip potential are shown in green. Results ordered by CoF on wet steel. ♣ = new since last report

3.3.4 CHEQUER PLATE RAMP TESTING

Chequer plate is a common profiled metal flooring, which is generally perceived to offer a high grip surface and is widely used for situations such as outdoor stairs, walkways and access steps to vehicles. However, surface roughness and pendulum tests have rated the surface as a moderate to high slip potential in water wet conditions. It was considered important to include this surface in the tests as it is commonly found in occupational environments, under the assumption that it will provide a slip resistant surface in a variety of conditions. All the footwear which gave a low slip potential on wet steel was retested on chequer plate to see if the surface profiles further improved slip resistance.

There are two main types of chequer plate in common use. There are many variations of pattern, and either steel or aluminium is commonly used for either. The designs can be seen in Figure 3.6.

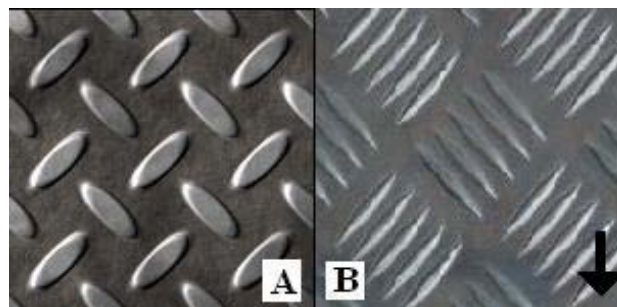


Fig 3.6 [A] Dur bar and [B] Five bar aluminium chequer plate

Five bar chequer plate is by far the more commonly installed floor so was selected for all the additional tests. As with all other testing parameters, the chequer plate floor surface is in new condition, and so will give an indication to the slip potential on a new surface. As the surface ages, rusts, oxidises, or wears smooth the slip potential will change. The black arrow indicates the direction of ramp testing.

The ramp testing results for chequer plate under water wet and glycerol contaminated conditions are given in Table 3.7, along with the corresponding results for steel sheet for comparison. These results are then presented graphically in Figures 3.8a and 3.8b.

Shoe	Steel / Water CoF	Steel / Glycerol CoF	Chequer Plate / Water CoF	Chequer Plate / Glycerol CoF
Shoes For Crews (8092, 8096)	0.52	0.31	0.51	0.27
Hyper V Sole Spider Max Black ♣	0.51	0.18	0.51	0.34
Keuka Café ♣	0.41	0.24	0.54	0.34
Slip Grips – Spider Grip sole (5332)	0.41	0.17	0.49	0.28
Inyati Wellington (127) ♣	0.39	0.11	0.57	0.23
TredSafe (Chef) ♣	0.38	0.18	0.58	0.26
Dunlop Purofort – High Grip	0.38	0.15	0.40	0.23
V6 Powerwear (V6000) ♣	0.37	0.10	0.27	0.18
Goliath Atomium (Atom63) ♣	0.37	0.14	0.35	0.20
Bata Industrials (Thor 705-69911) ♣	0.37	0.12	0.42	0.22
Uvex Classic (8451.9) – Ultra Grip sole	0.36	0.05	0.48	0.24
Globe Trotter Rigger Boot ♣	0.32	0.08	0.33	0.18
Inyati Wellington Clog ♣	0.25	0.07	0.61	0.25
Four-S Shoe	0.07	0.01	0.23	0.10

Table 3.7. Ramp test results for chequer plate with water and glycerol contamination. Shoes presenting a high slip potential are shown in red, shoes posing a moderate slip potential are shown in orange and a low slip potential are shown in green. ♣ = new since last report

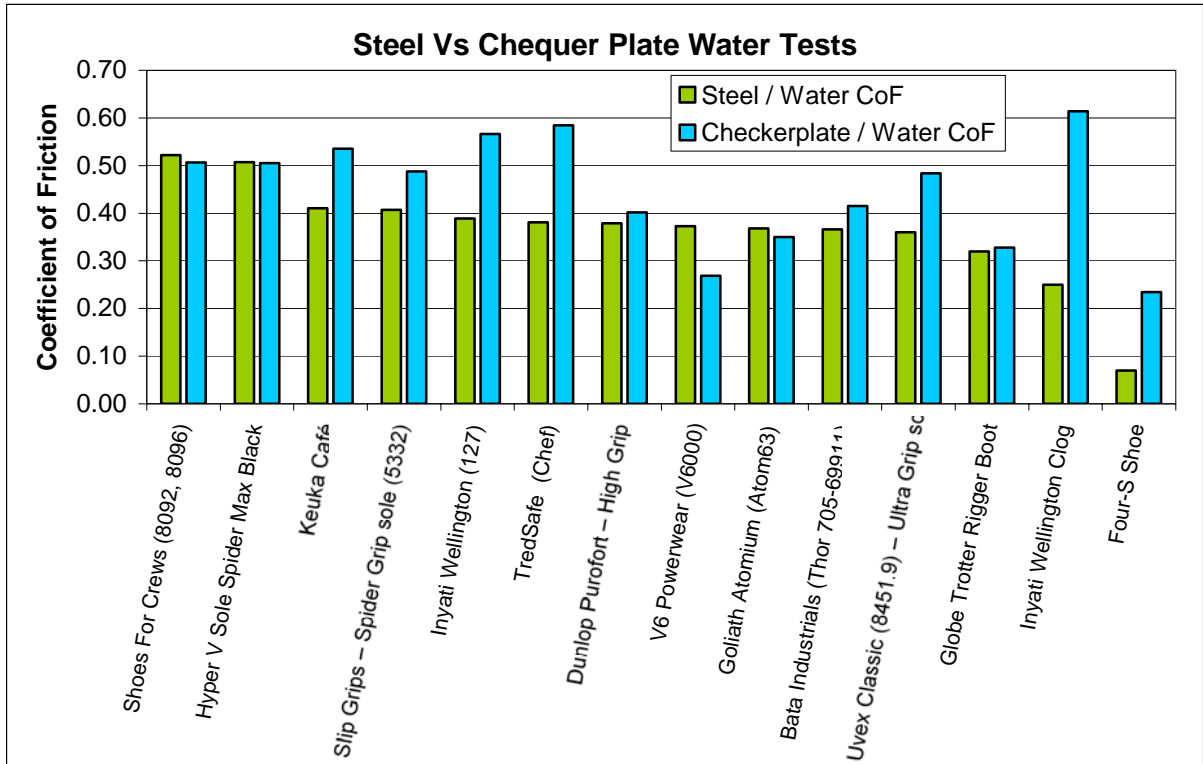


Fig 3.8a. Graphical comparison of shoe performance on steel and chequer plate with water contamination.

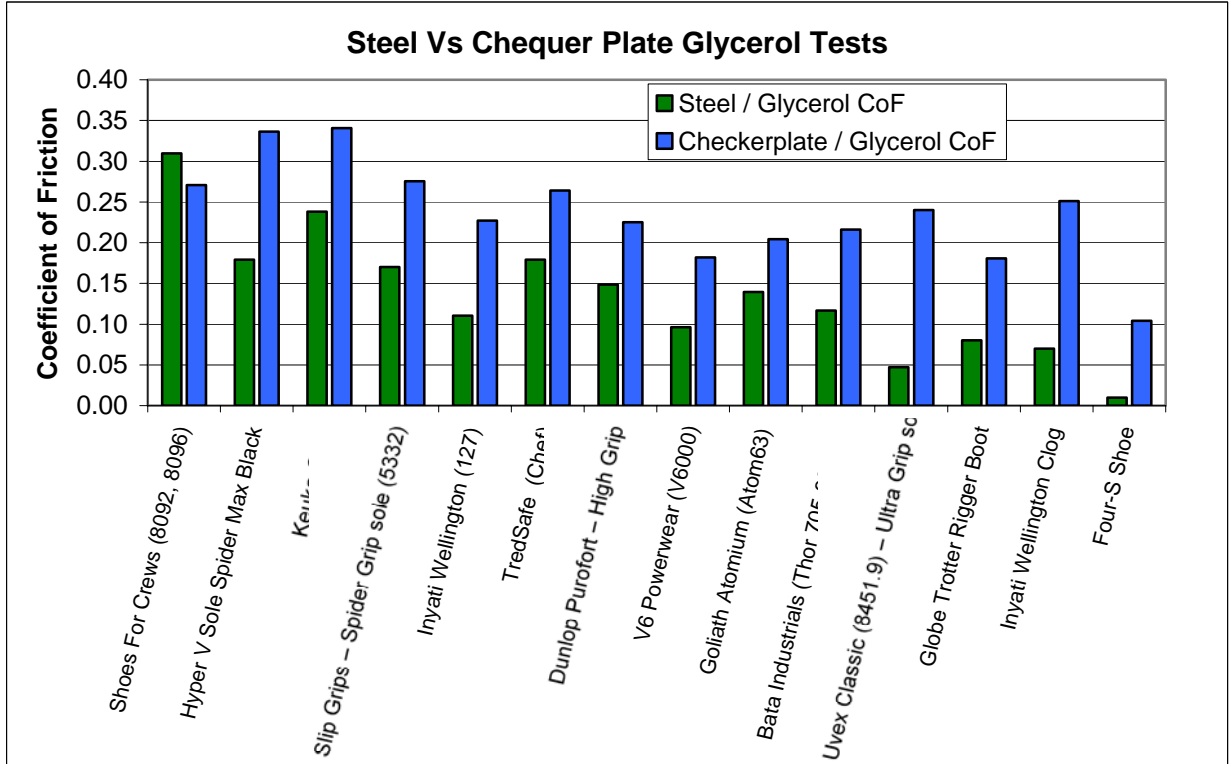


Fig 3.8b. Graphical comparison of shoe performance on steel and chequer plate with glycerol contamination.

The results show how the profiled surface offers different levels of slip resistance to different shoes under different contamination. For example:

- The Shoes For Crews appear unaffected by the pattern under both conditions. Although the results from the sheet steel are slightly higher than those for the chequer plate for both contaminants, the difference in performance is barely more than the error margins of the results.
- The V6 Powerwear seems to cope better with the water contamination on the smooth surface than on the profiled surface, but better with the glycerol contamination on the profiled surface.
- The Globetrotter rigger boots seem to cope equally as well with water on either surface, but much better with glycerol on the chequer plate than the smooth surface.
- The Inyati clog and the standard Four-S shoe show the most benefit from the profiled surface with both contaminants. The Inyati clog has a large block sole pattern, while the Four-S shoe has no tread pattern at all. These footwear fall at opposite ends of a hypothetical sole pattern scale, yet both gain much advantage from the profiled surface.

It would seem that there is much variability in the slip resistance of the shoes on chequer plate, due to the different soling patterns / materials of footwear, and possible influence of chequer plate pattern. Further work on the variations and directionality of the chequer plate pattern would be valuable. To gain a true picture of slip resistance it may be necessary to look at each individual combination of footwear, surface pattern and contamination as a unique situation. While the profile does not necessarily improve slip resistance, it may introduce other problems as a surface, e.g., movement of equipment, more difficulty in cleaning, and the pedestrians' perception that the surface is slip resistant when in fact it may be very slippery

The Four-S shoe has no tread pattern at all, so the interlock of surface and shoe pattern is almost completely removed, yet the chequer plate pattern offers a 3x improvement in slip resistance compared to the steel sheet. With the Inyati clog, there is a wide spaced, large block pattern, which seems ideal for physical interlock with the chequer plate pattern, a similar level of improvement is observed when compared to the steel sheet. Both surfaces have a similar surface roughness, but both the pendulum and ramp testing indicates that chequer plate is more slip resistant.

The results suggest that the profiled surface is advantageous when compared to sheet steel for glycerol contamination in the majority of cases, but is only advantageous for water-wet contamination in about 50% of cases. As the most common contaminant found in slip accident investigations is water, and water is used as the standardised contaminant for most slip assessment techniques, profiled surfaces such as chequer plate may be an important subject for further investigation.

3.4 SOLE CONSTRUCTION AND MATERIALS TESTING

3.4.1 SOLE HARDNESS

It is sometimes suggested that the hardness of the soling material can be used as an indicator of the slip resistance of footwear, with softer soling compounds generally being associated with better slip resistance.

Measurements of the International Rubber Hardness Degrees (IRHD) hardness of soling materials for each shoe were taken using a Durotech M202 digital hardness durometer and compared to the coefficient of friction results to determine if there was any correlation observed. The results can be seen in Table 3.9. Where the material of construction of the sole was known, this is also included.

Shoe	Marketed As Slip Resistant	Steel / Water CoF	Sole Construction (where known)	Hardness (IRHD)
Shoes For Crews (8092, 8096)	Yes	0.52	Weltd Rubber	43.83
Hyper V Sole - Spidermax Black	♣ Yes	0.51	Rubber	61.67
Keuka Café Softer Soles	♣ Yes	0.41	Rubber	53.67
Slip Grips – Spider Grip sole (5332)	Yes	0.41	Rubber	60.00
Inyati Wellington (127)	♣ Yes	0.39	PVC / Nitrile Rubber	65.56
TredSafe (Chef)	♣ Yes	0.38	Rubber	61.06
Dunlop Purofort – High Grip	Yes	0.38	Nitrile Rubber	67.94
V6 Powerwear (V6000)	♣ No	0.37	Thermo Plastic Urethane / P. U.	77.72
Goliath Atomium (Atom63)	♣ Yes	0.37	Dual Density P.U.	70.22
Bata Industrials (Thor 705-69911)	♣ No	0.37	Dual Density P.U.	77.11
Uvex Classic (8451.9) – Ultra Grip sole	No	0.36	Nitrile Rubber Outer / P. U. Core	79.17
Schurr A (1133301)	Yes	0.35	Rubber with cork inclusions	71.72
Aimont Safety Shoe (774400)	No	0.35		70.67
Bata Safemaster	Yes	0.34	Nitrile Rubber	75.83
Emma Venus	No	0.34	Dual Density P.U.	78.06
ABS (ABS220P)	Yes	0.33	P.U.	57.61
Keuka Café Overshoe	♣ Yes	0.33	Rubber	53.56
Tuskers 632 Unisex Safety Shoe	♣ Yes	0.33	Single Density P.U.	55.61
Centek (FS140)	No	0.32		74.61
Uvex Quattro – (8411.2)	No	0.32	Nitrile Rubber Outer / P. U. Core	66.06
Otter 93609	♣ No	0.32	Thermo Plastic Urethane / P.U.	65.78
Globe Trotter Rigger Boot	♣ No	0.32	Dual Density P.U.	65.67
Arco Sandyderm – Cofra Aderplus sole (6641)	Yes	0.31	Single Density P.U,	62.11
Cofra Minorca Safety Shoe Cofra Wave Sole	♣ Yes	0.30	Thermo Plastic Urethane / P.U.	64.33
Otter 98402	♣ No	0.30	Thermo Plastic Urethane / P.U.	66.72
Tuf (P5600)	No	0.29	Dual Density P.U.	65.22
Footsure Mudguard Gibson (FS65)	No	0.29	Thermo Plastic Urethane	74.60
Jalas Tandem Sport Geox (5910)	No	0.29		67.33
Tuskers Aquagrip Boot 388	♣ Yes	0.28	Dual Density P.U.	63.17

Shoe	Marketed As Slip Resistant	Steel / Water CoF	Sole Construction (where known)	Hardness (IRHD)
Sievi Solid XL+	No	0.28		58.72
Dunlop Purofort Rig Air	No	0.28		60.06
Jallatte Jaldonnel SAS Boot. Tritane sole	No	0.27	Dual Density P.U.	68.22
Gaston Mille Louisiana Clean Sole	No	0.27		72.28
Arco Boot - Cofra Supergrip "Flag sole" (F88)	Yes	0.26	Nitrile Rubber Outer / P.U. Core	70.22
Inyati Clog	No	0.25	PVC / Nitrile Rubber	70.33
Panther Dakota (21094 14 S3)	No	0.25		70.33
Bata Hazmax (892-77210K)	Yes	0.25	Vulcanised Rubber	74.00
Arco Basics Wellington	No	0.25	PVC / Nitrile Rubber	69.61
Cofra Stanton Off-Road Sole Safety Boot	No	0.23	Nitrile Rubber Outer / P.U. Core	63.61
Heckel MC Silver Boot (Z12300)	No	0.23		69.33
Bacou Bac run 783 safety Boot	No	0.23		70.89
Ruff Lander (S17)	No	0.23	Vulcanised Rubber	71.94
Ruff Lander (S64)	No	0.20	Vulcanised Rubber	71.50
Ergoli / Inyati CB4 Boots	No	0.20		68.06
Precision Wheat Ankle Boot (8801)	Yes	0.18	Nitrile Rubber Outer / P. U. Core	80.00
Dr. Martens Grip Trax	Yes	0.18	Rubber Outer / P. U. Core	70.00
Magnum Patrol	No	0.18	Nitrile	64.67
Precision Black Trainer (5500)	Yes	0.17	Dual Density Phylon / Nitrile rubber	74.00
Quiva (Quiva 06/A)	Yes	0.15	Thermostatic	60.67
Dr. Martens Tred safety Chukka Boot (6G8100)	Yes	0.15	Nitrile Rubber	67.33
Trojan Elite H64 Black Safety Shoe	No	0.13	Rubber	71.56
Four-S Shoe	No	0.07	Four-S rubber	94.00

Table 3.9. Ramp results for all the shoes on steel with water contamination. Shoes presenting a high slip potential are shown in red, shoes posing a moderate slip potential are shown in orange and a low slip potential is shown in green. Results ordered by CoF on wet steel. Hardness measurements in degrees Shore.

Most of the recorded hardness falls within the range 55-80 degrees Shore. Four-S rubber was developed to represent a shoe soling material of moderate slip resistance, and have a standard hardness of 96±2 degrees Shore. The hardest footwear tested other than Four-S measured 80 degrees Shore. If we were to assume that hardness is related to slip resistance, and that harder shoes were more slippery, we would expect from this that all the shoes perform better than the Four-S shoe. This appears to be the case. However, this would be an unfair comparison, as the Four-S shoe does not have any tread pattern to offer physical interlock with the surface.

There appears to be no obvious relationship between hardness of the sole material and slip potential on wet steel. The better performing shoes tend to have rubber soles, moderate shoes tend to be polyurethane soles, while poorer performing shoes tend to be nitrile, but there is no distinct rule obvious from these results. The results are presented graphically in Figure 3.10.

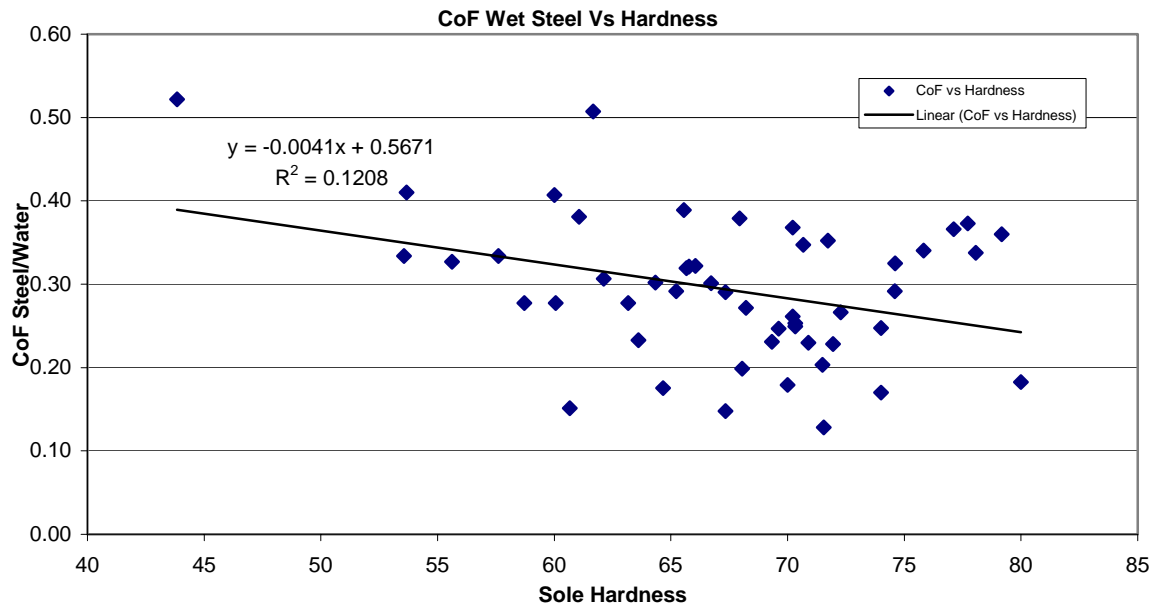


Fig 3.10 Graphical presentation of CoF on wet steel vs sole hardness. Note that the Four-S shoes are not plotted on the graph, only the occupational footwear.

From Figure 3.10 we can see that there is a slight trend of increasing hardness leading to a decrease in the coefficient of friction on wet steel, but with R^2 0.1208, this is not a statistically significant relationship.

To better illustrate, the ramp CoF results from wet steel were plotted against sole hardness measurements, as in Figure 3.10, but with each soling material identified and separated. These results can be seen in Figure 3.11.

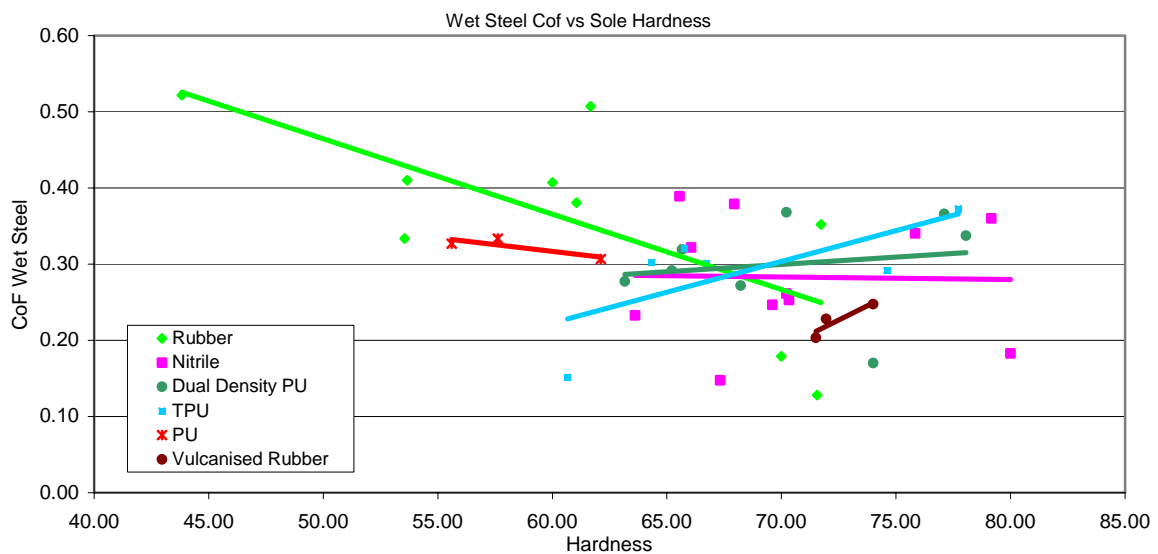


Fig 3.11. Graphical presentation of CoF on wet steel vs sole hardness. Note that the Four-S shoes are not plotted on the graph, only the occupational footwear. Results are coded by primary soling material. Best-fit lines are also displayed.

The best-fit lines help us see some tentative patterns in the results. The higher up the graph a plot appears the greater the slip resistance of that footwear on wet steel, the further to the right of the graph the harder the soling material. It is evident that the soling material used affects the slip resistance offered by the footwear.

3.4.2 SOLE MATERIALS

The better performing shoes tested tend to be rubber soles, which best show the decreased slip resistance with increased material hardness. Polyurethane soled shoes tend to be moderately slip resistant, with the red line in the centre of the graph suggesting moderate hardness and moderate slip resistance. Nitrile, dual density polyurethane and vulcanised rubber tended to have lower performance, with the lines at the harder / low slip resistance end of the graph.

TPU, or Thermo Plastic Urethane also falls into the harder material / low slip resistance category, but one result (hardness = 60, CoF =0.16) makes the trend line suggest that increasing hardness actually improves slip resistance on wet steel. If we were to disregard this single result the trend line would be roughly parallel with the dual density polyurethane and the nitrile trend lines.

The hardness of a soling material will be intimately linked with the type of material used, and we can assume that both material type and material hardness of a shoe sole will affect the slip resistance. There are a number of linked variables which are influencing the results; each piece of footwear has a different soling material, sole pattern, sole hardness, wear rate etc. The only controlled variables from these tests are the test surface, water contaminant and the test procedure.

3.4.3 SOLE PATTERN

There is evidence that the soling pattern can affect slip resistance. In previous work (HSL Report PED/05/04, 2005) two patterns of Schurr shoes (A and B) were tested. The following results were given as in Fig. 3.12.

Shoe	Steel/Water	Steel/Glycerol	Vinyl/Water	Vinyl/Glycerol	Quarry/Water	Quarry/Glycerol
Schuerr B	0.38	0.08	0.84+	0.15	0.7	0.23
Schuerr A	0.36	0.06	0.84+	0.15	0.51	0.17

Fig 3.12. Various results for Schurr A and Schurr B shoes from previous study.

Both shoes have the same soling material and hardness but a different tread pattern. The test values are the same for both contaminants on the vinyl surface, the steel tests differ only by the acceptable error of the test, but the quarry tile tests differ by a significant margin, indicating that the sole pattern may be affecting the results, but that the effect is dependent upon the test surface.

3.4.4 ISOLATING HARDNESS

It has been suggested that the slip resistance of footwear is dependent upon several variables, including soling material, tread pattern and hardness. If very similar shoes are selected, to try to limit some of these variables, better correlations should be achieved. There are several footwear in this study of a similar type of soling pattern and all of which have soft rubber soles, examples of which are shown in Fig. 3.13.

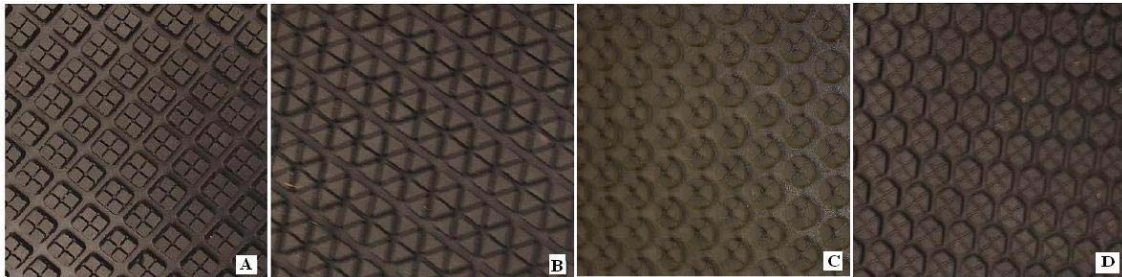


Fig 3.13. Examples of the selected footwear soling patterns: Shoes For Crews (A) Hardness = 43.83, Keuka Café (B) Hardness = 53.67 Slip Grips (C) Hardness = 60.00 and Tredsafes (D) Hardness = 61.06.

As can be seen, the soling patterns are very similar for each of these shoes. Each comprises of many small raised blocks with multiple leading edges. A similar plot to those shown in Fig 3.11, but using only the results for Shoes For Crews, Keuka Café, Slip Grips and Tredsafes is presented in Fig. 3.14 below.

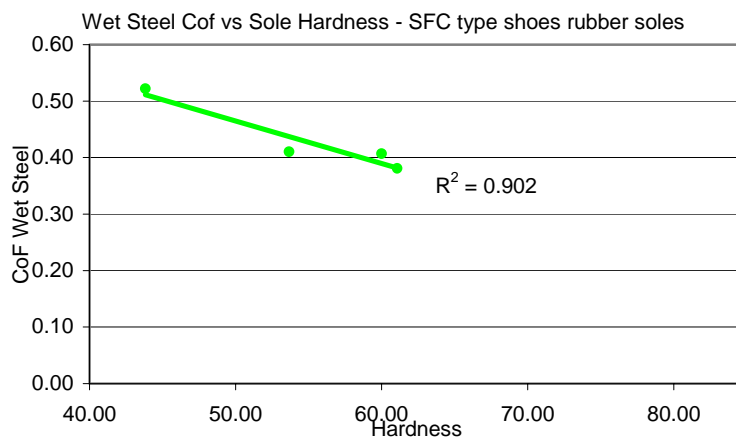


Fig 3.14. Graphical presentation of CoF on wet steel vs sole hardness for soft rubber soled shoes with similar soling patterns. Best-fit lines are also displayed, along with the R^2 correlation.

Although the data set is very small, a correlation can be seen between the hardness of the soling material and the CoF on wet steel. It is unclear whether the critical factor is the soling pattern, the type or hardness of the soling material, or some other factor which may have been overlooked.

There is evidence from this and previous work that the hardness of a soling material can affect the slip resistance of footwear. During this work the compound of the Keuka Café footwear was changed to a softer rubber. The softer compound rubber soled shoes offered more slip resistance than the older version.

3.4.5 SUMMARY

These results suggest that although hardness on its own does not give close correlation to slip resistance, the hardness of a sole material may be used along with other information as an indicator to slip resistance of footwear. If other factors are constant or known, differences may be identified by varying hardness, soling pattern or soling material. The data suggests that softer soling materials offer greater slip resistance than harder soling materials, but also that soling pattern may have an effect. It could be suggested that footwear manufacturers could improve the slip resistance of their product simply by using softer compounds for the soling materials.

This is an area where further work would be valuable. If some manufacturers were willing to produce prototype footwear using, for example, the same tread pattern and material type but of different hardness, investigations could give a valuable insight into the effects of these variables on the slip resistance of footwear.

4 CONCLUSIONS

The ramp testing suggests that there is an increasing number of shoes available in the marketplace that provide a good level of slip resistance in water contaminated conditions even on highly demanding surfaces such as sheet steel. The study also highlighted the comparative lack of shoes that perform well with more viscous contaminants such as glycerol.

Results suggest that sole materials and construction cannot easily be used to predict the slip potential of footwear independently of other factors. The results are clearly indicative that soft rubber soles offer the best slip resistance on all surfaces tested.

STEEL AND WATER

The most slip resistant shoes on wet steel are listed alphabetically below:

Bata Industrials (Thor 705-69911)
Dunlop Purofort
Goliath Atomium (ATOM63)
Hyper V Sole - Spidermax Black
Inyati Green Wellington (127)
Keuka Café Softer Soles
Shoes For Crews
Slip Grip
TredSafe (chef shoe)
Uvex Classic
V6 Powerwear (V6000)

All of these shoes presented a low slip potential on wet steel.

STEEL AND GLYCEROL

The top performing shoes on steel contaminated with glycerol were Shoes for Crews, which presented a moderate slip potential, all the other shoes tested presented a high slip potential.

QUARRY AND WATER

All the shoes used in the initial study were shown to present a low slip potential on wet quarry tile, and so it has been assumed that the new shoes will perform similarly.

QUARRY AND GLYCEROL

The most slip resistant shoes on quarry tiles contaminated with glycerol are listed alphabetically below:

Inyati Wellington (127)
Keuka Café
Keuka Café Overshoe
Shoes For Crews (8092, 8096)
Slip Grips – Spider Grip sole (5332)
TredSafe (Chef)
Tuskers 632 Unisex Safety Shoe

All of these shoes presented a low slip potential on glycerol contaminated quarry tile.

CHEQUER PLATE AND WATER

Of the footwear which gave a low slip potential on wet steel, the most slip resistant types on wet aluminium chequer plate are listed alphabetically below:

Bata Industrials (Thor 705-69911)
Dunlop Purofort – High Grip
Hyper V Sole Spider Max Black
Inyati Wellington (127)
Inyati Wellington Clog
Keuka Café
Shoes For Crews (8092, 8096)
Slip Grips – Spider Grip sole (5332)
TredSafe (Chef)
Uvex Classic (8451.9) – Ultra Grip sole

All of these shoes presented a low slip potential on wet chequer plate.

CHEQUER PLATE AND GLYCEROL

Of the footwear which gave a low slip potential on wet steel, the most slip resistant types on aluminium chequer plate contaminated with glycerol are listed alphabetically below:

Hyper V Sole Spider Max Black
Keuka Café
Shoes For Crews (8092, 8096)
Slip Grips – Spider Grip sole (5332)
TredSafe (Chef)

All of these shoes presented a moderate slip potential on glycerol contaminated chequer plate.

When the footwear that performed best on wet sheet steel was tested on wet chequer plate, the data generated suggests that chequer plate does not necessarily offer improved slip resistance over unprofiled equivalents, but in only one case did the chequer plate have a significant adverse affect. When glycerol was the contaminant, the results for the same footwear on chequer plate did show an improvement over those on sheet steel in almost every case.

5 FUTURE WORK

The data presented here is current at the time of writing, but footwear is continually under development, and new shoes come to the marketplace all the time. In order to ensure that the data available to regulatory inspectors remain current it would be advisable to check regularly to ensure that the shoes are still widely available, to retest some brands and to test newly available footwear. It may also be valuable to use other test methods, such as the BS EN 13287 test, to allow comparison with the ramp test results and possibly provide a clearer indication of the slip resistance of the footwear.

The limited amount of testing undertaken on chequer plate highlighted a potential future avenue to investigate more thoroughly. The commonly held belief that chequer plate offers a surface of suitable slip resistance for demanding outdoor conditions and frequently wet areas appears contestable. Some footwear performed better on water-wet chequer plate compared to sheet steel, although in many cases there was no improvement. However, with glycerol contamination, 12 of the 13 shoes tested performed better on chequer plate than on steel sheet. As this is a surface often used in outdoor situations, water contamination is likely to be common, but many other contaminants, such as mud or oil, may also be possible.

It would seem, however, that there is likely to be much variability in slip resistance performance, possibly due to the different patterns of chequer plate and soling patterns / materials of footwear, and so it may be necessary to look at each individual combination of footwear and chequer plate surface as a unique situation. Furthermore, the pendulum test results suggested a high degree of directionality with this surface, which further demonstrates the variability of the slip resistance offered by these profiled surfaces. HSL has recently been commissioned to investigate the effects of pendulum slider dimensions for the assessment of chequer plate surfaces, and further ramp based work may also be of interest.

The results presented here suggest that sole construction and material hardness are unreliable as a method for predicting slip potential. The data gathered on sole construction is generally taken from the advertising and product descriptions, and may not be entirely accurate. If patterns or trends in these properties could be established to quickly assess the slip potential of shoes it could make the process of selecting suitable shoes for a particular situation much simpler and cheaper. Although

initial work in this area has given mixed results, the effort and cost involved with including assessment of these factors into future studies similar to this one should be minimal.

Production of shoes similar to the Four-S shoe but with differing hardness to eliminate any influence of sole pattern or material variation, would allow investigation into the effect of sole hardness independent of sole material or tread pattern. If some manufacturers were prepared to produce prototype footwear using, for example, the same tread pattern and material type but of different hardness, or to produce footwear of differing tread patterns with identical sole materials, investigations could give a valuable insight into the effects of these variables on the slip resistance of footwear.

6 REFERENCES

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APPENDIX 1

A1.1 INTERPRETATION OF SURFACE ROUGHNESS RESULTS USING UKSRG GUIDELINES

Rz Surface Roughness (μm)	Water-Wet Slip Potential
Below 10 μm	High Slip Potential
10 - 20 μm	Moderate Slip Potential
20 + μm	Low Slip Potential

A1.2 INTERPRETATION OF PENDULUM RESULTS USING UKSRG GUIDELINES

Pendulum Test Value	Slip Potential
0 - 24	High Slip Potential
25 - 35	Moderate Slip Potential
36 +	Low Slip Potential

A1.3 INTERPRETATION OF RAMP RESULTS USING UKSRG GUIDELINES

Ramp Coefficient of Friction	Slip Potential
0 – 0.25	High Slip Potential
0.26 – 0.35	Moderate Slip Potential
0.36 +	Low Slip Potential

A1.4 RELIABILITY OF FOUR-S / SLIDER 96 PENDULUM AND RAMP TEST RESULTS

Four-S rubber is used as a standard test rubber which should be reproducible across tests. The pendulum and ramp test data should be similar to corroborate the test methods as complimentary, reproducible and representative. Below is a table comparing the Four-S results from the tests carried out.

	Rz	Pendulum	Ramp
Wet Steel	1.5	0.08	0.07
Wet Quarry	17.4	0.42	0.59
Wet Chequerplate	2.9	0.25	0.23

The results suggest that the Four-S pendulum and ramp test results support each other better for the metal surfaces than the quarry tile. As this report is not concerned with the water-wet quarry tile surface, only the glycerol, this should not affect the confidence in the steel sheet and aluminium chequer plate tests.

APPENDIX 2

A2.1 ESTIMATION OF EXPERIMENTAL ERRORS IN RAMP TESTING

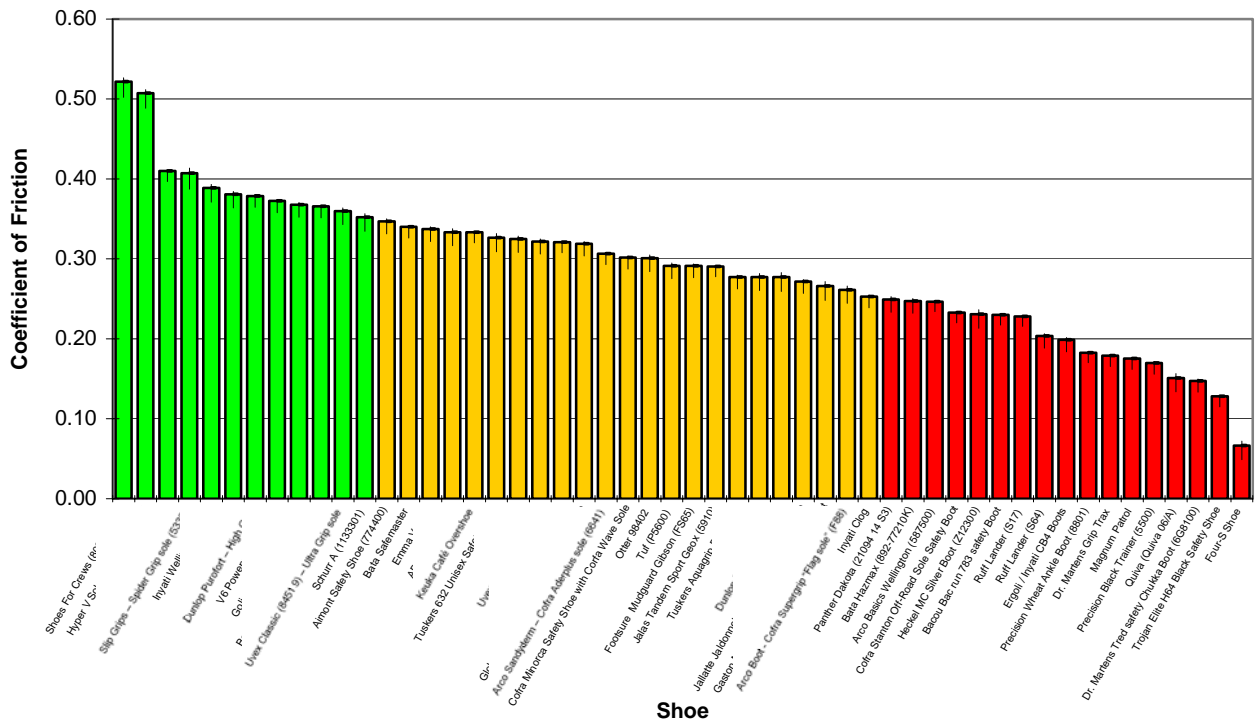
Under the ramp operating procedure outlined in HSL-PS-SOP12 each ramp operator generates 12 ramp angles, the highest and lowest of which are then discarded and the remaining values are averaged to give the critical angle. The friction coefficient between the particular combination of footwear, flooring and contaminant is then calculated by simply taking the tangent of the critical angle.

This procedure is then repeated by a second operator and the results are accepted if the mean angles achieved by the two operators are within 2° of each other. This 2° externally applied constraint and the fact that only two data points are generated for each combination mean that the ramp data is not readily amenable to many conventional statistical analysis methods. However it is possible to examine the widest range of critical angle results that would have been accepted under the standard operating procedure and to determine if it would have resulted in the reclassification of any of the footwear investigated in the study.

Each of the coefficients of friction values reported here were generated by averaging the tangents of the critical angles generated by the two ramp operators. Hypothetically, if the lowest of those two critical angles had been generated first during testing a second critical angle of up to 2° lower would have been accepted, and the coefficient of friction then calculated from those angles. Similarly, if the highest critical angle had been generated first a critical angle up to 2° higher would have been accepted.

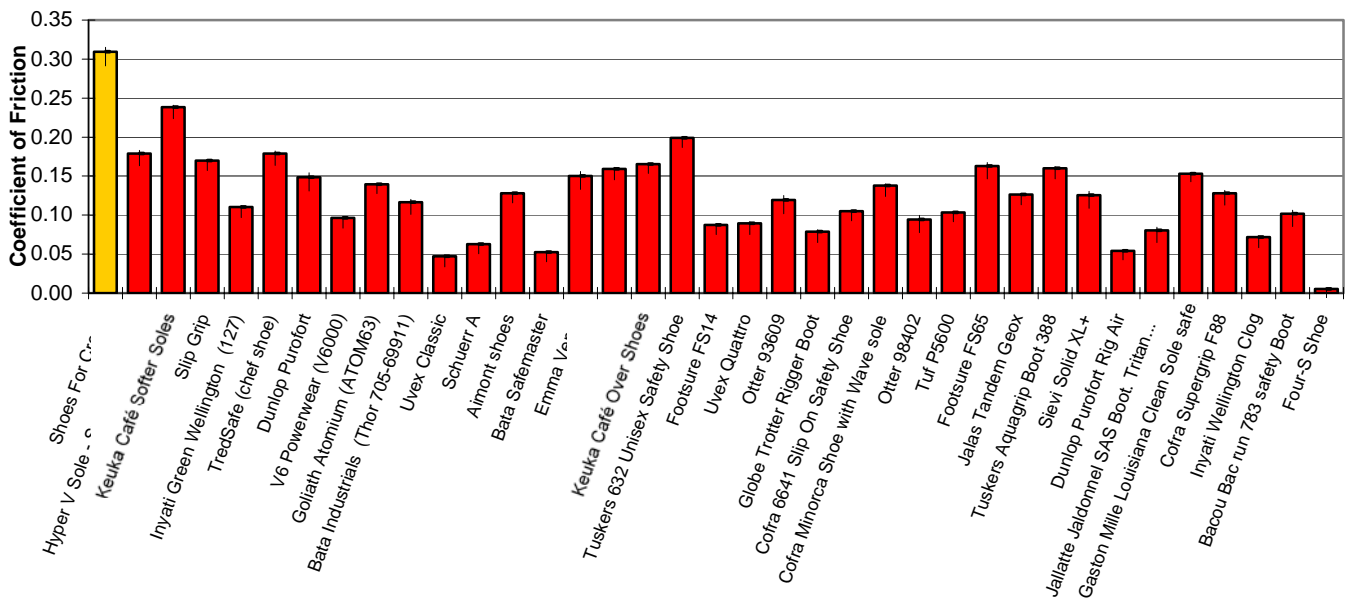
These hypothetical lowest and highest possible values are illustrated in the graphs below as the black lines. The bars denote the actual coefficient determined during the study; shoes presenting a high slip potential are shown in red, shoes posing a moderate slip potential are shown in yellow and a low slip potential are shown in green.

A2.2 STEEL AND WATER RESULTS



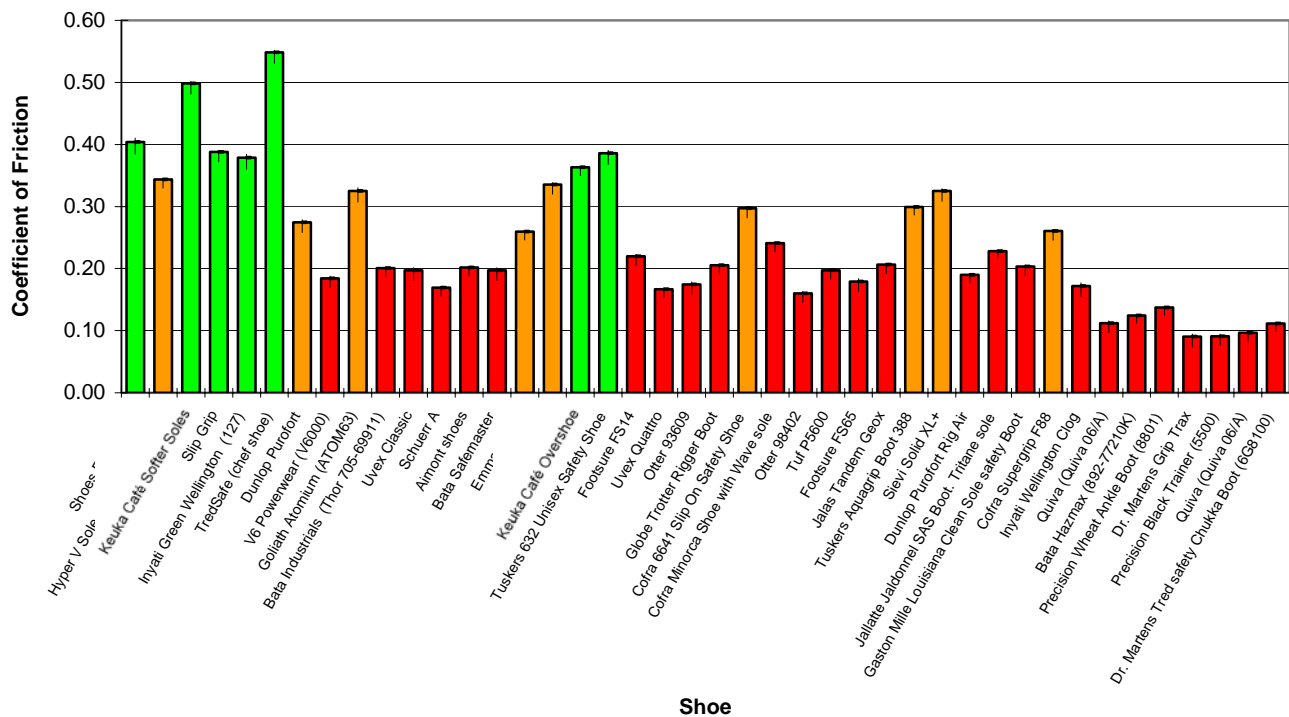
Of all the shoes tested in the study the acceptance of the hypothetical data would have resulted in the reclassification of 8 pairs of shoes, where if the lowest theoretical value had been recorded 4 would have classed as presenting a moderate slip potential as opposed to a low slip potential, and 4 would have classed as presenting a high slip potential as opposed to a moderate slip potential. If the highest theoretical value had been recorded it would not have resulted in the reclassification of the any of the shoes tested.

A2.3 STEEL AND GLYCEROL RESULTS



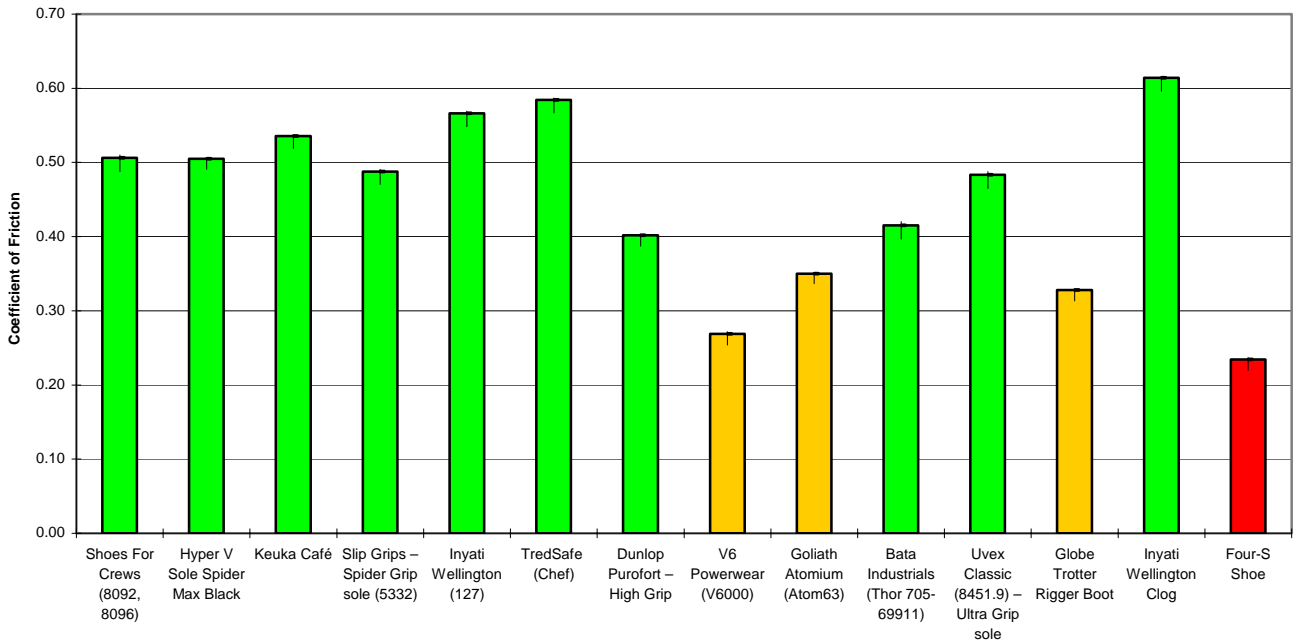
For the steel and glycerol results acceptance of the hypothetical data would not have resulted in the reclassification of the any of the shoes tested.

A2.4 QUARRY AND GLYCEROL RESULTS



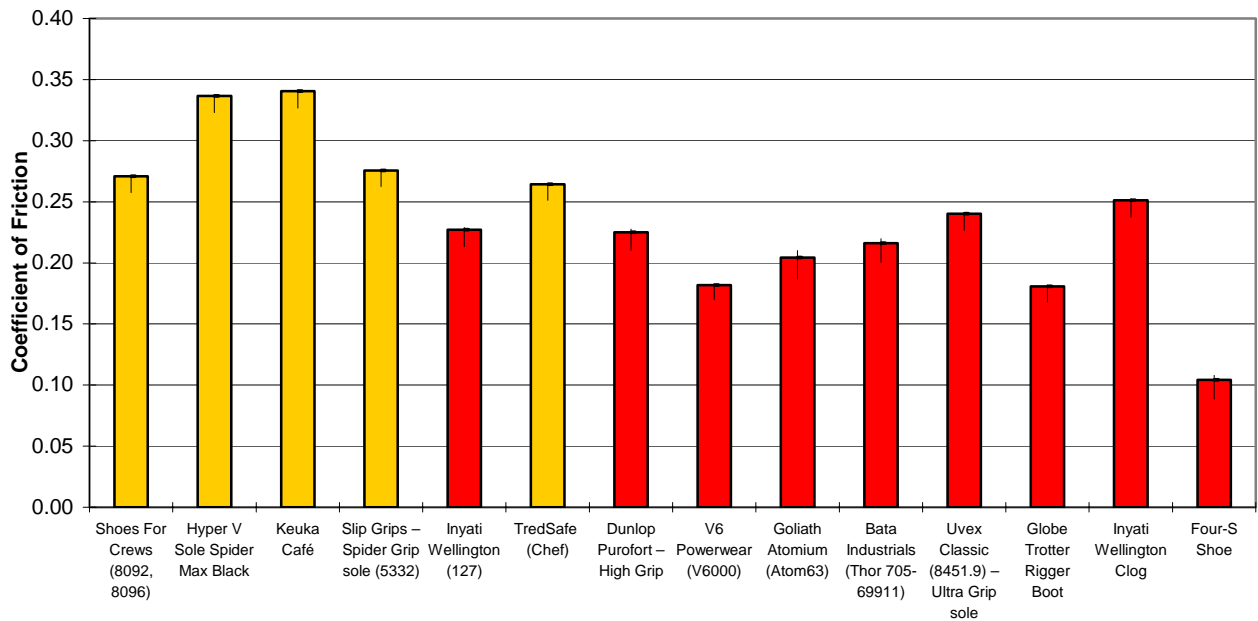
For the quarry tile and glycerol results acceptance of the hypothetical data would have resulted in the reclassification of the 4 pairs of the shoes. If the lowest theoretical value had been recorded, 2 shoes would have been classified as presenting a high slip potential as opposed to a moderate slip potential, and 1 moderate rather than low slip potential. If the highest theoretical value had been recorded 1 type of shoe would have been classified as presenting a moderate slip potential as opposed to a high slip potential.

A2.5 CHEQUER PLATE AND WATER RESULTS



For the chequer plate and water results acceptance of the hypothetical data would have resulted in the reclassification of the 1 pair of the shoes tested, where if the lowest theoretical value had been recorded the shoes would have been classified as presenting a high slip potential as opposed to a moderate slip potential.

A2.6 CHEQUER PLATE AND GLYCEROL RESULTS



For the chequer plate and glycerol results acceptance of the hypothetical data would have resulted in the reclassification of the 2 pair of the shoes tested, where if the lowest theoretical value had been recorded the shoes would have been classified as presenting a high slip potential as opposed to a moderate slip potential.