THE ANTISLIP CONCEPT AND THE PERFORMANCE OF CERAMIC FLOORS

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SUMARY

At the present Civil Construction Industry development stage in Brazil, many shortcomings are found with regard to the safety parameters applied to products. In the particular case of ceramic floors, the issue of safety during use is still relatively unexplored. This is in contrast to the importance given to safety by other countries, such as USA, Italy, Great Britain, France, Germany, Australia, and Japan among others.

In view of the increased knowledge of factors involving ceramic floor safety during use, an investigation of the factors relating to the slip phenomenon was conducted in this work. It was based on two points: a literature survey and tests accomplished according to the international standards on this subject.

The analysis of the results obtained in these tests and the comparison of theses with those related in the searched literature clearly showed the importance of the knowledge of the antislip properties of the floors used in residences. The results also serve as a first guide to ceramic floors, with regard to the way they meet performance and quality requirements.

1. INTRODUCTION

Slip can be defined as an intense decrease in the coefficient of static friction value between the moving body and the support surface, occurring in a very quick manner. According to SACHER (1993) [1] the slip act can be defined as a loss of equilibrium caused by an unexpected, unforeseen and out of control slip of the foot. It is usually a final product of an insufficient frictional coefficient.

This researcher defines the frictional coefficient as being an inherent property of the interface of the materials in contact, depending in turn on the micro and macro roughness of these materials, of the force (inter and intra molecular) of repulsion and attraction, and even of their viscosity/elastic properties. Thus, factors such as contact area, time of contact before the occurrence of the movement, speed of the movement, or even pressure between the materials represent elements of influence in the frictional coefficient.

There are two distinct kinds of frictional coefficient: the static friction coefficient and the dynamic friction coefficient. Both of them can be defined as a result of a relationship among the normal forces produced by the supporting surface and the forces of friction, static in the case of the coefficient of static friction, and kinetic in the case of the dynamic friction coefficient.

The property through which a surface can resist or give protection to slip is defined according to SACHER (1993) [1], as its "Slip Resistance". This can be explained by several parameters, the frictional coefficient probably being the most important of these.

The resistance to the slip is a property that needs to be faced with caution, since it is not a characteristic inherent to the surface material. Moreover, it is not constant in all use conditions, since it depends on a series of factors related either with the used material or with the way the user interacts with the surface during use.

2. TEST METHODS USED TO DETERMINE THE CHARACTERISTICS OF ANTISLIP CERAMIC FLOORS

According to STRANDBERG (1983) [2], the two main problems related to the appraisal of floor antislip properties are: in first place, the lack of validity and reliability of the results obtained by means of trials accomplished between the shoe sole and the passage surfaces. And in second place, the difficulties in the determination of proper security criteria and limits for friction required in different situations of floor use.

Thus, the devices and methods used in these determinations shall reproduce the conditions found in the most critical stages of people's walk movement, especially soon after heel contact with the surface. Based on tribology 1 and practical experience, STRANDBERG (1983) [2] considers that the method to determine the floor antislip properties should take into account the following variables:

(I) Tribology is part of the science that deals with frictional force measurements (AURÉLIO ELETRÔNICO, 1994)

[1] SACHER, A. *Slip Resistance and the James Machine 0.5 Static Coefficient of Friction - Sine Qua Non.* ASTM Standardization News, v. 22, n.8, p.52-59, 1993.

[2] STRANDBERG, L. *On accident analysis and slip-resistance measurement.* Ergonomics, v. 26, n. 1, p. 11-32, 1983.

	Tortus	AFNOR P 90.106	AFNOR P 61.515	AFNOR P 61.516	Swedish Standard[(II)]
Test principle	Displacement of the trial element at constant speed	Pendulum	Person on bent surface	Artificial foot on bent plane	Reproduction of foot movement
Observation	Straight coefficient measurement	Elevation of the pendulum arm	Person's slip	Foot's slip	Shoe slip
Measure	Tangential force	Elevation of the pendulum arm	Angle of bent plane	Angle of bent plane	Vertical/ horizontal force graphic based on time
Speed Measurement	1,7 cm/s	270 cm/s	--	Very slow	--
Vertical load	Constant: 0,2 daN	Variable: 2 daN medium	Variable: between 30 and 100 daN	Constant: 2,3 daN	Variable: from 0 to 100 daN
Shape of measurement element	Disc of 9 mm diameter	Bent 76x25 mm	Foot	Disc of 150 mm diameter	Shoe
Material of the measurement element	Shoe sole	Rubber 55° shore A	--	Rubber 86° shore A	Shoe heel
Measurement in other materials	Yes	Yes	No	Yes	Yes
Measurement *in situ*	Yes	Yes	No	No	No
Measured roughness	All	Flat	All	All	All
Minimum dimension of the floor	40x40 cm	20x10 cm	120x60 cm	200x60 cm	40x10 cm
Dependence on surface temperature	No	No	Yes	Yes	Yes
Dependence on surface heating	Yes	No	Yes	Yes	Yes

Table 1. *Comparison among the measurement methods of the dynamic frictional coefficient used in Europe (DE RICK, 1991)*

- Time of contact with the surface, which is related with the kind of surface and its drainage capacity of contaminating substances;
- Foot angle, which influences the determination of the most critical part of the shoe;
- Point of application of the force of contact on the shoe;
- Vertical force, which determines the correct pressure to be applied on the contact area;
- Slip speed, which will determine the correct dynamic of the forces of friction.

For BOWMAN (1992) [3] the development of a test method shall go through the following stages:

(II) Swedish Standard SS 92 35 15: Floorings, Determination of slip resistance.

[3] BOWMAN, R. *Slip Resistance - Which Way Should the Dice Fall?* Ceramic Engineering & Science Proceedings: Materials & Equipament / Whitewares, v. 13, n. 1-2, p. 46-65, 1992.

- Choice of equipment project criteria, based on exhaustive studies of specialized literature;
- Selection of one or more proper materials to be used in the trial element;
- Determination of one or more proper environments to trial accomplishment with reasonable accuracy, stability and reproducibility of results;
- Establishment of trial procedures which allow the obtainment of accurate, valid and reproducible values.

In Table 1, DE RICK (1991) [4] makes a comparison among the several test methods used to determine the frictional coefficient of ceramic floors normally used in Europe.

3. EXPERIMENTAL APPRAISAL OF ANTISLIP CHARACTERISTICS OF CERAMIC FLOORS

This section will appraise and describe the results obtained during the experimental stage of the study, on conducting the "A" and "B" methods set out by the INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO) (1995) [5]. In order to have a better comprehension of the results, and with a view to allowing a better comparison among the values obtained and those found in the literature search, it was decided to divide the ceramic floors into five basic categories, according to the classification followed by CARANI et al. (1992) [6]. Thus, the ceramic floors were divided into *non-antislip glazed, antislip glazed, non-antislip non-glazed, antislip non-glazed with surface texture, and antislip non-glazed with surface relief.*

The criteria used for this classification were the information given about the recommended use for each kind of specific floor by the respective manufacturers. Thus, only those floors were considered as being antislip, which were described in this way by the manufacturers. Besides the "normal" ceramic floors, i.e., those with 3% water absorption, two materials of Italian origin were also tested, ceramic stoneware and porcelain stoneware. Two other kinds of floors were furthermore tested, which compete with ceramics in specific uses: Goiás stone (on swimming pool decks) and flat concrete (in escape routes and on building emergency stairs). Table 2 describes this classification.

Thus, for a better identification, the tested floors were divided into the following groups:

- Group 1: non-antislip glazed ceramic floors, represented in the attached graphics by the yellow color;
- Group 2: antislip glazed ceramic floors, represented in the attached graphics by the green color;

[4] De Rick, J. C. *Slipperiness of floor surfaces and measurement of the coefficient of friction.* Ceramica Acta, v. 3, n. 4-5, p. 11-33, 1991.

[5] International Organization for Standardization. *Ceramic tiles - Part 17: Determination of coefficient of friction - ISO/DIS 10545-17.* Geneve, 1995.

[6] Carani, G. et al. *Slip Resistance of Ceramic Floor Tile: Design Criteria for Antislip Tile.* Ceramic Engineering & Science Proceedings: Materials & Equipament / Whitewares, v. 13, n. 1-2, p. 1-13, 1992.

- Group 3: antislip non-glazed ceramic floors, represented in the attached graphics by the pink color;

- Group 4: non-antislip non-glazed ceramic floors, ceramic stoneware, porcelain stoneware, Goiás stone and flat concrete, represented in the attached graphics by the blue color.

Kind of floor	Code
Non-antislip glazed	C1, C2, C4, C5, C6, C7, C8, P1, P2, P3, P4, E1
Antislip glazed	C3, C9, C10, C11, C12, E2, G1, G2
Non-antislip non-glazed	G3
Antislip non-glazed with surface texture	E3
Antislip non-glazed with surface relief	G4
Ceramic stoneware	Stoneware
Porcelain stoneware	Porcelain
Goiás stone	Stone
Flat concrete	Concrete

Table 2. *Classification of tested floors*

For the performance of the tests, the ISO (1995) [5] guidelines were followed. In the case of the dynamic tests, the "A" method was used, while the "B" method was used to establish the static frictional coefficient values. The values obtained for the dynamic frictional coefficient (III) under dry condition are illustrated in Appendix A. The values obtained under wet condition are shown in Appendix B. Appendix C presents the values found for the static frictional coefficient (IV) under dry condition, while the corresponding values obtained under wet condition are illustrated in Appendix D.

4. ANALYSIS OF THE OBTAINED RESULTS

Considering the limits imposed by ISO (1995) or the ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (1995) [7] for the static test, the tested floors can be classified according to the results presented Table 3, where the approved and rejected total of each floor group is listed.

Classification	Group 1	Group 2	Group 3	Group 4
Total tested	12	8	2	5
Total approved	0	6	2	3
Total rejected	12	2	0	2

Table 3. *The sum total of static test results under wet conditions.*

(III) The minimum value for the dynamic frictional coefficient is 0,4 (ISO, 1995).

(IV) The minimum value for the static frictional coefficient is 0,5 (ISO, 1995).

[7] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. *Placas cerâmicas para revestimento. Determinação do coeficiente de atrito de pisos* - PROJETO 02:002.10-017. Rio de Janeiro, 1995.

—ASSOCIATION FRANÇAISE DE NORMALISATION. *Essai des revêtements de sol céramiques - determination des propriétés antidérrapantes* - AFNOR P 61-515. Paris, 1983.

- Essai des revêtements de sol céramiques - determination des propriétés antidérrapantes - pièce et zones de travail fortement exposées au risque de glissement - AFNOR P 61-516. Paris, 1983 b.
- Sols Sportifs: Mésure de la glissance d'une surface a l'aide d'un pendule de frottement - AFNOR P 90-106. Paris, 1986.

Through this table it is possible to verify that the sum total of samples in Group 1 did not reach the minimum ISO (1995) [5] values. With regard to the other groups, the values found were very different. In Group 2 only 25% of the floors were rejected, while none was rejected in Group 3, against 40% of the floors in Group 4, which did not reach the minimum value specified by the standard.

Thus, considering only the static test method, and taking into account the division proposed by the mentioned regulation (class 1 for floors used in normal facilities, and class 2 for floors recommended for places where resistance to slip is required), the classification of the tested floors would be the following:

- Class 1 would contain the following floors: C1, C2, C3, C4, C5, C6, C7, C8, C12, P1, P2, P3, P4, E1, STONEWARE and CONCRETE;
- Class 2 would be composed by the following floors: C9, C10, C11, E2, E3, G1, G2, G3, G4, PORCELAIN and STONE.

The total sum of approved and rejected floor tiles in each floor group by the dynamic test is listed in Table 4.

Classification	Group 1	Group 2	Group 3	Group 4
Total tested	12	8	2	5
Total approved	3	8	2	5
Total rejected	9	0	0	0

Table 4. *The sum total of dynamic test results under wet conditions.*

Through this table it is possible to verify that only 25% of the tested samples in Group 1 reached the minimum values specified by the ISO (1995) [5]. In relation to the other groups the values found were quite compatible, or rather, in all cases the approval percentage was 100%.

Thus, following only the dynamic method, the tested floors can be classified as follows:

- Class 1 contains the following floors: C1, C2, C4, C5, C6, C7, C8, P1 and E1;
- Class 2 contains the following floors: C3, C9, C10, C11, C12, P2, P3, P4, E2, E3, G1, G2, G3, G4, STONEWARE, PORCELAIN, STONE and CONCRETE.

On analyzing the previous data, a difference can be observed in both classifications (static and dynamic). While the dynamic method admits 18 floors in class 2, the static trial has classified only 11 floors as being resistant to slip. It seems that the trial which follows method "B", the one specified by the ISO (1995) [5], is more rigorous than the one specified in method "A".

With a view to appraising the performance of the ceramic floors found in the Brazilian market, it was observed that the total samples which did not satisfy the minimum requirements prescribed by the ISO (1995) [5] for the dynamic test was quite big within Group 1 and zero in the other groups. Initially, this fact made us believe that

[5] International Organization for Standardization. *Ceramic tiles - Part 17: Determination of coefficient of friction - ISO/DIS 10545-17*. Geneve, 1995.

national antislip floors fully reached regulation requirements, however the reality is quite different. Even inside these standard limits, these floors represent a certain risk in terms of safety, according to the classification proposed by BOWMAN (1992) [3]. For this researcher the tested floors, according to dynamic method under wet condition, would be placed in the following classification:

- Poor: C1, C2, C4, C5, C6, C7, C8, P1 and E1;
- Medium: C3, C12, P2, P3, P4, STONEWARE, PORCELAIN and CONCRETE;
- Good: C11, E2, G2 and G3;
- Very Good: C9, C10, G1 and G4.

The differences observed in classification are due to the fact that the ISO (1995) [5] nowadays considers only two value averages for the dynamic frictional coefficient, or rather, bigger and smaller than 0,4, while the criteria proposed by this researcher are more rigid, according to levels previously proposed by ISO itself, as it can be seen in the work of CARANI et al (1992) [6], where there was a total of four classifications for floors. Here it could be observed that the minimum acceptable value for the dynamic frictional coefficient of a floor would be 0,5 for it to be considered an antislip one. Still according to this work, the minimum acceptable value for the dynamic frictional coefficient in ceramic floors would be 0,3 which therefore excludes some of the floors tested.

According to HARRIS; SHAW (1988) [8] the surfaces that present frictional coefficients of less than 0,2 are considered insecure, while those which present frictional coefficient between 0,2 and 0,4; can be considered below acceptable safety levels. On the other hand, the floors that present frictional coefficient values between 0,4 and 0,75, as well those presenting values above 0,75 are respectively considered satisfactory for normal use and "proper for places where special care is required",

The inclusion of the test method called static to the purpose of ISO 10545-17 [5], which deals specifically with ceramic frictional coefficient measurements is believed to be due to, above all, to the fact that this test method has been utilized for a long time in the United States (since the beginning of the century), and thus consists of a quite traditional method whose results are even part of American law about the safety of floors used in residences (PATER apud REDFERN; BIDANDA, 1994).[9]

However there is a discussion involving several researchers who consider that the static method does not provide valid values under all use conditions, among them STRANDBERG (1983) [2] and PERKINS; WILSON (1983) [10]. For them, the dynamic

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[2] STRANDBERG, L. *On accident analysis and slip-resistance measurement.* Ergonomics, v. 26, n. 1, p. 11-32, 1983.

[3] BOWMAN, R. *Slip Resistance - Which Way Should the Dice Fall?* Ceramic Engineering & Science Proceedings: Materials & Equipament / Whitewares, v. 13, n. 1-2, p. 46-65, 1992.

[5] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. *Ceramic tiles - Part 17: Determination of coefficient of friction - ISO/DIS 10545-17.* Geneve, 1995.

[6] CARANI, G. ET AL. *Slip Resistance of Ceramic Floor Tile: Design Criteria for Antislip Tile.* Ceramic Engineering & Science Proceedings: Materials & Equipament / Whitewares, v. 13, n. 1-2, p. 1-13, 1992.

[8] HARRIS, G. W.; SHAW, S. R. *Slip resistance of floors: user's opinions, Tortus instrument readings and roughness measurement.* Journal of Occupational Accidents, v. 9, n. 2, p. 287-298, 1988.

[9] REDFERN, M. S.; BIDANDA, B. *Slip resistance of the shoe-floor interface under biomechanically-relevant conditions.* Ergonomics, v. 37, n. 3, p. 511-524, 1994.

[10] PERKINS, P. J.; WILSON, M. P. *Slip resistance testing of shoes - new developments.* Ergonomics, v. 26, n. 1, p. 73-82, 1983.

frictional coefficient values correspond to a closer view of the reality of the use of floors and in this way they provide more important appraisements with regard to the potential of floor slip.

In fact, it can be said that slip generally happens during the occurrence of a movement, and in this way the measurement of the dynamic frictional coefficient would really be more important than the static one. Nevertheless, observing the values obtained in both used methods, it is concluded that, at least in the tested floors to date, the static method showed itself to be more rigorous than the dynamic one, besides using simpler equipment.

Concerning the occurrence of contaminating elements, on which work was done in PROCTOR; COLEMAN (1988) [11], it was found that the presence of these elements on floors represents a determining factor for the slip occurrence in 56% of the researched events. Thus, the occurrence of water on internal floors was singled out in 33% of the events as a danger factor, therefore being ranked first amongst the factors of risk, while the presence of ice, snow and water in the external environment to the building was ranked second, with 15% of the events, just ahead of the occurrence of oils on the floor which represented 8% of the occurrence of slip risk factors. These numbers demonstrate that the maintenance of building facilities is a factor of extreme importance in avoiding accidents and consequently a very important safety factor.

This opinion is also shared by PROCTOR (1993) [12], who in his work emphasizes the importance of correct maintenance of the built environment, so that user safety can be preserved, since according to this researcher, about 40% of the falls that occur on the same level are caused by slip, which makes this kind of accident perfectly avoidable in most cases. An example is the case of external areas or areas close to entries, where designing an effective drainage system is important, to avoid the aquaplaning phenomenon.

5. CONCLUSIONS

The method called static showed itself more rigorous in the results found than the dynamic method, since some floors approved by method "A" were not approved by method "B", as the presented results show. However, the tested range does not allow affirming that this would be a more accurate test method. Actually, a greater number of determinations, with many more samples, would be needed in order to conclude something about it.

Referring to the change in the classification of the floors found in the INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (1995) [5], one of the reasons could be credited to the "cleaning advantages" factor. As analyzed by BÖHNER [13] et al (1991) in his work, the greater the roughness or even the harder the surface profile, the more difficult is the removal of contaminating material on the floor.

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[5] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. *Ceramic tiles - Part 17: Determination of coefficient of friction - ISO/DIS 10545-17*. Geneve, 1995.

[11] PROCTOR, T. D.; COLEMAN, V. *Slipping, Tripping and Falling Accidents in Great Britain - Present and Future.* Journal of Occupational Accidents, v. 9 ,n. 4, p. 269-285, 1988.

[12] PROCTOR, T. D. *Slipping accidents in Great Britain - an update.* Safety Science, v. 16, n. 3-4, p. 367-377, 1993.

[13] BÖHNER, B. ET AL *Cleanability of Slip Resistant Tiles.* Tile & Brick Int., v. 7, n. 4, p. 238-242, 1991.

In this case the determination of the roughness level of a surface consists of a good complement to the investigation of floor antislip properties, as can seen through the analysis of the work of HARRIS; SHAW (1988) [8], where it is considered that under wet situations the roughness condition is equally important, since it will be responsible for slip resistance, either by the liquid drainage or by keeping effective contact between shoe soles and passage surface, besides serving as a good indication of its cleaning capacity.

Taking into account the work of CARANI et al (1992) [6], it can noted that the values found in the tests performed let us believe that the national production is not too far from that found in Europe. However, it is worth remembering that national floors which do no have antislip behaviour showed themselves in certain circumstances to be extremely dangerous, besides presenting minimum values of the frictional coefficient below 0,3. In some cases reductions occurred between the dry and wet dynamic coefficient of friction, in which the difference between the values exceeded 50%.

6. APPENDIX

APPENDIX A

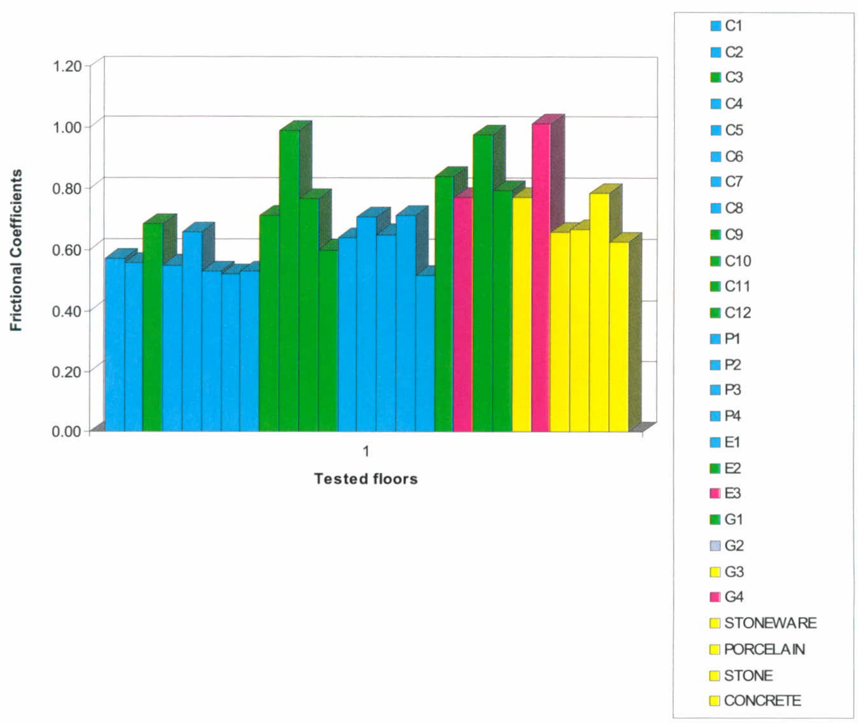

Figure 1. *Dynamic frictional coefficients under dry condition.*

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[6] CARANI, G. ET AL. *Slip Resistance of Ceramic Floor Tile: Design Criteria for Antislip Tile.* Ceramic Engineering & Science Proceedings: Materials & Equipament / Whitewares, v. 13, n. 1-2, p. 1-13, 1992.

[8] HARRIS, G. W.; SHAW, S. R. *Slip resistance of floors: user's opinions, Tortus instrument readings and roughness measurement.* Journal of Occupational Accidents, v. 9, n. 2, p. 287-298, 1988.

APPENDIX B

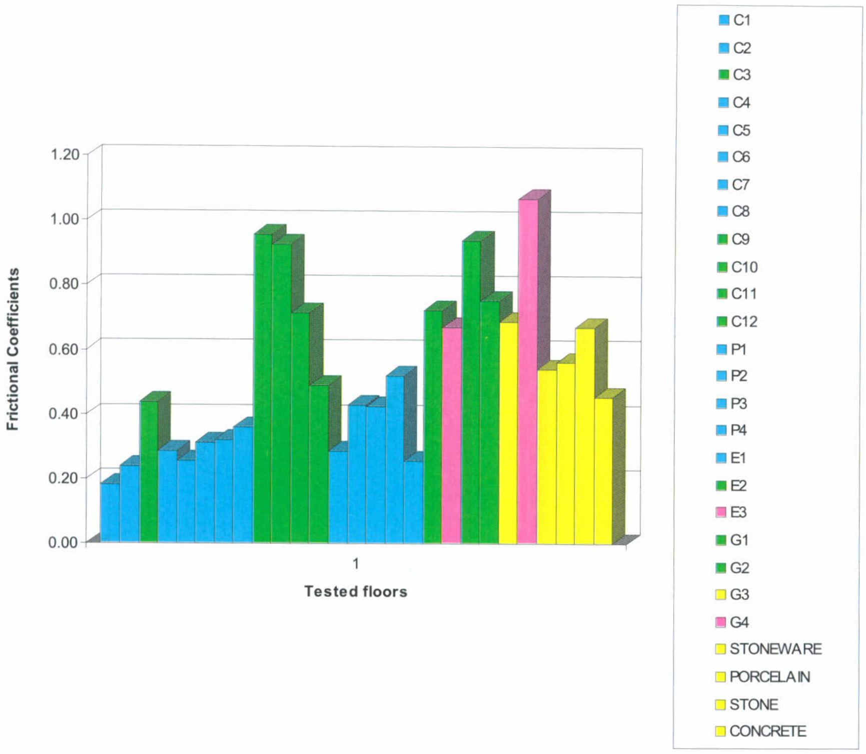

Figure 2. Dynamic frictional coefficients under wet condition.

APPENDIX C

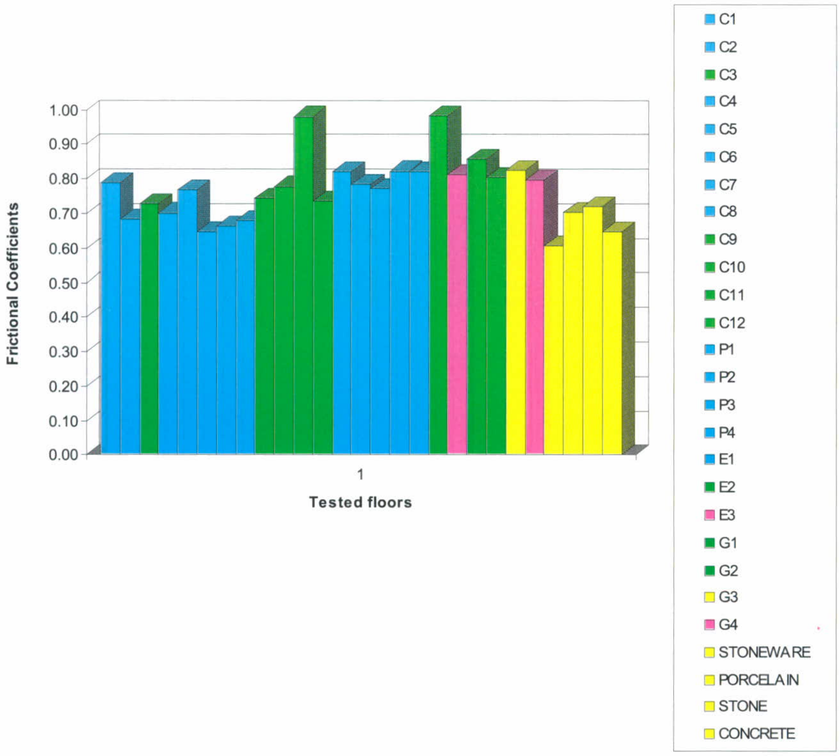

Figure 3. Estatic frictional coefficients under dry condition.

APPENDIX D

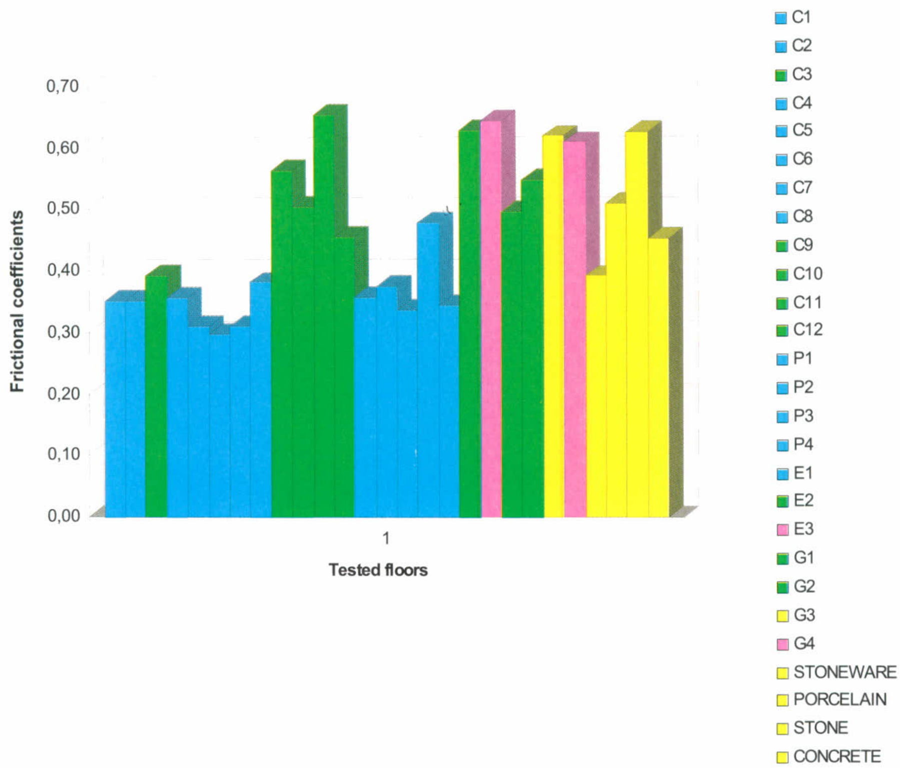

Figure 4. *Static frictional coefficients under wet condition.*