TESTING OF SKID RESISTANCES
OF
HARD FLOOR SURFACES
USING VARIOUS SHOE HEEL MATERIALS

by

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A Thesis Submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Master of Science
in Home Economics

Greensboro
June 1965

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APPROVAL SHEET

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HODGES, MARIANNE BERRY. Testing of Skid Resistances of Hard Floor Surfaces Using Various Shoe Heel Materials. (1964) Directed by: Mrs. Savannah S. Day. pp. 87

The purposes of this study were as follows:

1. To determine the coefficients of friction between hard floor surfaces (ceramic tile, terrazzo, concrete, and aggregate) and various heel materials (leather, rubber, rubber crepe, Neolite, and nylon).

2. To determine the effect of three different floor polishes (standard, clear, and skid resistant) on the coefficients of friction of hard floor surfaces.

3. To determine the effect of applied moisture on the coefficients of friction of unpolished and polished hard floor surfaces.

A friction testing apparatus was used to measure the force of kinetic friction of the unpolished and polished hard floor surface materials with various heel materials. A weight load of 25 pounds was used on each heel. The new, worn, and polished floor materials were tested dry and with moisture applied.

Analysis of variance was the method employed in analyzing the data. Three separate analysis of variance models were used: (1) An analysis of the dry unpolished and polished hard floor surface materials, (2) an analysis of the new and worn (unpolished) hard floor surface materials with moisture applied, and (3) an analysis of the polished hard floor surface materials with moisture applied.

From the results of this study the following conclusions were drawn:

1. There were some differences in skid resistance among the hard floor surface materials tested. Terrazzo was the least skid resistant and aggregate the most skid resistant when unpolished or polished as compared to the other materials. Glazed ceramic was generally the least skid resistant and quarry tile was generally the

most skid resistant when unpolished or polished with moisture applied.

2. There was marked differences in skid resistance among the five heel materials tested. Under all conditions leather was generally less skid resistant and rubber crepe more skid resistant than the other heel materials.

3. Hard floor surface materials and heel materials did not have a single force of friction measurement but rather the force of friction measurement depended upon the hard floor surface materials to which the various heels were applied.

4. Polishes generally lowered the skid resistance of hard floor surface materials, especially the clear and skid resistant polishes with moisture applied.

5. The skid resistant polish did not generally show more skid resistant properties either dry or with moisture applied than the standard and clear polishes with leather, nylon, and rubber heels. The skid resistant polish did show skid resistant properties for the Neolite and rubber crepe heels when tested under dry conditions.

6. Moisture generally lowered the skid resistance of unpolished and polished hard floor surface materials.

ACKNOWLEDGMENTS

It is with sincere appreciation that the writer wishes to acknowledge the guidance and assistance of the following persons without whom the completion of this study could not have been accomplished:

To Mrs. Savannah S. Day, her able director, Mrs. Madeleine B. Street, Dr. Anna J. Reardon, and Dr. Aden C. Magee, her gratitude for their endless time, patience, and unfailing cooperation.

To her mother and brother, her appreciation for their encouragement and faith and

In memory of her father, a profound gratefulness for the education which he enabled her to have.

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CHAPTER I

INTRODUCTION

During the past 40 years, attempts have been made to determine the skid resistant properties of various flooring materials. Results of previous experiments have indicated significant differences in the skid resistance of various types of resilient floor coverings. Hard floor surfaces are also widely used as flooring and there is a need for information concerning the skid resistance of these flooring materials.

In public buildings and in residential areas such as hallways, bathrooms, kitchens, and entryways one might find a substantial use of the hard floor surface materials such as terrazzo, ceramic tile, and polished concrete floor surfaces. The waxing of these materials with any of several polishes and with the possible combination with moisture found in these areas, offers another dimension in the slip resistance problem.

The effect of different shoe heel materials worn in combination with hard floor surface materials should also be considered, especially since some heels are known to have a slipping characteristic while others have a gripping characteristic. Information is limited on the testing of various heel materials with hard floor surfaces under various conditions.

This study seeks to determine the skid resistant character of a combination of floor materials, heel materials, and floor polishes.

I. THE PROBLEM

Statement of the Problem

The purposes of this study were: (1) to determine the coefficients of friction between hard floor surfaces (ceramic tile, terrazzo, concrete, and aggregate) and various heel materials (leather, rubber, rubber crepe, Neolite, and nylon);[1] (2) to determine the effect of three different floor polishes on the coefficients of friction of hard floor surfaces; (3) to determine the effect of applied moisture on the coefficients of friction of unpolished and polished hard floor surfaces.

Importance of the Study

A common fear of the elderly and of parents of young children is the potential hazard of slipping and falling. This hazard, which may be considered a safety problem among all ages, may be associated with many different causes such as feebleness or type and condition of floor or heel. Not all factors affecting walking safety can be controlled. However, the more easily controlled factors are probably in the choice and maintenance of flooring materials and in the choice of heel materials.

This study of the skid resistance of hard floor surfaces should have implications both for consumers and manufacturers regarding hard floor surface materials, heel materials, and floor polishes.

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[1]These and other definitions are contained in the Glossary in Appendix A.

CHAPTER II

REVIEW OF THE LITERATURE

In this chapter a review of previous studies in the field of slip resistance testing will be presented with an emphasis on hard floor surface testing as well as some of the techniques and testing instruments which have been used.

I. STUDIES OF THE SKID RESISTANCE OF FLOOR SURFACE MATERIALS

In 1926 an investigation was made by the National Bureau of Standards of 148 specimens of walk-way and floor materials.[1] The development of a process and an apparatus for preparing specimens of walk-way surface materials for friction measurements resulted from the investigation. In addition, methods and the Hunter apparatus for measuring coefficients of friction were developed. Because of the incompleteness of the research, two years later 24 specimens were chosen from the original group for a two year investigation. The specimens covered "extreme ranges in hardness, smoothness, compressibility, absorptive power and other characteristics affecting the coefficient of friction . . ."[2]

The measurement employed for determining the resistance to slipping between shoe sole and the walk-way surface was the coefficient

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[1]R. B. Hunter, "A Method of Measuring Frictional Coefficients of Walkway Materials," Bureau of Standards Journal of Research, V (August, 1930), pp. 330-331.

[2]Ibid.

of friction. The friction measuring apparatus operated on an oblique thrust principle which was supposed to correspond to the thrust on the shoe in walking. Since it was recognized that a number of variable conditions affect the coefficient of friction between a shoe sole and walk-way surface, a variety of surface materials were used under varied controlled conditions including those simulating actual service conditions.[3]

The hard surface materials used were smooth-faced natural stone products, such as slate, marble, and travertine, and one specimen of vitrified tile. Some artificial stone products were also used, some of which contained a hard abrasive in the mixture. Since the products were referred to by letter, their actual identity was not discernible and the data could not be interpreted for specific materials. However, some generalizations could be made about a particular group of products in comparison with other products used. For instance, the coefficient of friction for one of the smooth-faced natural stone products was always lower than that of a particular resilient material when tested with different weights or with an increasing area of contact. The coefficient of friction was also lower for one of the artificial stone products when compared with a particular resilient material under the dry condition but was higher under the wet condition for both this particular product as well as another resilient product. However, the coefficients of friction among the artificial stone products were not consistently lower than those of the resilient materials under dry conditions.[4]

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[3]Ibid.

[4]Ibid.

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[3] Ibid.

[4] Ibid.

There was a definite range in the coefficients of friction among the seven products identified as natural stone products but they were all lower than the various resilient floor materials except for one.[5]

The original investigation sought to develop a satisfactory method for measuring the frictional resistance of walkway materials.[6] However, the data collected in the 1928 study, were limited in their direct application to a safety provision for walkway surfaces because the different determinations of the coefficients of friction of the same materials were spread. Also, there was possible error in determining the minimum coefficient needed for safety.[7]

In 1947 the mechanics of walking were studied by the National Bureau of Standards in order to aid in the design of testing instruments. A pendulum impact testing instrument (Sigler Slip-Tester) was designed based upon the assumption that, "in the process of ordinary walking, slipping is most likely to occur when the rear edge of the heel contacts the walk-way surface."[8]

Five different types of hard floor surface materials were used in the 1947 study along with other types of flooring materials. The hard surface group included: a concrete slab, ground with silicon carbide; a cement-mortar topping, worn smooth; terrazzo, worn smooth;

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[5] _Ibid_.

[6] Percy A. Sigler, Martin N. Geib, Thomas H. Boone, "Measurements of the Slipperiness of Walkway Surfaces," _Journal of Research of the National Bureau of Standards_, XL (May, 1948), p. 339.

[7] Hunter, _op_. _cit_., p. 339.

[8] Boone, _loc_. _cit_.

terrazzo, containing alundum grit, worn smooth; and quarry tile, worn smooth. Of all the tests between walkway surfaces and dry and wet rubber or leather heel materials, terrazzo, containing alundum grit and worn smooth, showed the best antislip properties for a dry rubber heel. Terrazzo, worn smooth, showed the poorest antislip properties with a wet leather heel. The coefficient of friction was always higher for the rubber heels than for the leather heels under both dry and wet conditions for all the hard floor surface materials used. With rubber heels the coefficient of friction was always higher for the heels when they were dry. With the leather heels the coefficient of friction was higher for the wet heels on the concrete slab and lower for quarry tile, cement-mortar, and terrazzo.[9]

The Sigler apparatus and method of testing were used again in 1959 for slipperiness tests on conductive flooring samples (those which depend either completely or partially on the presence of acetylene black or carbon) with leather and rubber heels under both wet and dry conditions.[10] It was noted in these tests that:

> . . . Slipperiness is not a constant of the walkway surface alone, but is a function of both surfaces and is materially affected by their conditions. Therefore, an unqualified evaluation of a particular floor or floor finish may be very misleading.[11]

The results also showed that the higher the coefficients of friction, the less slippery was the surface. The antislip characteristics

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[9]Ibid., p. 345.

[10]Thomas H. Boone, et al., "Conductive Flooring for Hospital Operating Rooms," Journal of Research of National Bureau of Standards, reprint.

[11]Ibid.

of the conductive materials were also found to be comparable to those of the corresponding nonconductive materials.[12]

The results of the 1947 study were substantiated by the 1959 tests with the terrazzo floorings. The coefficients of friction were always higher with dry leather and rubber heels on terrazzo than with the same wet heels. The coefficients of friction were also always higher with dry and wet rubber heels on terrazzo as compared with dry and wet leather heels.[13]

In the 1950's a study was conducted in Norway on the measurements of human reaction to hardness of floor coverings.[14] Included in this study were measurements of the coefficient of friction of various flooring materials (concrete, vinyl tile, rubber, sheet vinyl, cork tiles, linoleum, varnished Norway spruce, terrazzo, and honed limestone) made by pulling weighted leather and rubber soles along the floor. Partial results indicated that the minimum safety value of the coefficient of kinetic friction of a floor material, ought to be not less than 0.20 and not more than 0.40 for leather soles.[15]

With dry leather soles, the coefficients of static friction were highest with concrete, but the coefficient of kinetic friction was

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[12] Ibid.

[13] Ibid.

[14] R. Schjodt, "Measurements of Human Reaction to Hardness of Floor Covering," Authorized Reprint from the copyrighted ASTM Bulletin No. 247, July 1960. Published by the American Society for Testing Materials, Philadelphia 3, Pa.

[15] Ibid.

highest with the rubber floor material. There were no tests between wet leather soles and hard floor surface materials.[16]

The coefficients of static and kinetic friction of the dry rubber soles were highest for concrete. Wet rubber soles were not tested with the hard floor surface materials.[17]

New synthetic brands of heels added to the market in recent years have not been reported in the literature on hard floor surface testing. The types of heels which have been tested have been limited to leather and rubber.

In a paper presented to the Chemical Specialties Manufacturers' Association in 1961, Dr. J. Vernon Steinle, a member of the 1947 Bureau of Standards Committee and research director of Johnson's Wax, Inc., summarized research methods, apparatus and findings relative to the slipperiness of walkway surfaces.[18] With regard to hard floor surfaces Dr. Steinle said:

> . . . the exposed surfaces of wax are practically identical in their physical properties regardless of the underlying surface, and also in general, the coefficients of friction of hard floorings are lower than those of the wax coating, that is, they are more slippery unwaxed than waxed.[19]

II. TESTING INSTRUMENT AND TECHNIQUE DEVELOPMENT

Various instruments and numerous procedures for testing have

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[16]Ibid.

[17]Ibid.

[18]J. Vernon Steinle, "Waxed Floors Are Safe," Soap and Chemical Specialties, (September, 1961), p. 81.

[19]Ibid., p. 82.

been devised to measure the coefficient of friction of walk-way surfaces. The most commonly employed machines are the James and the Sigler. The Sigler machine is a dynamic pendulum impact testing instrument. The pendulum, having a mechanical shoe at the lower end, sweeps a shoe material over the walkway surface to be tested. Test heel materials of rubber and leather are attached to the underside of the shoe. The coefficient of friction of the two materials can be determined from a point recording.[20]

The James machine, developed by Underwriters Laboratory, measures the static coefficient of friction and is not suitable for use on wet, rough or corrugated surfaces.[21] The portable Dura tester, according to Berkeley and Burns, compares favorably with the James machine results and is of special value because of the speed of operation, automatic feature and use of easily prepared test heels.[22]

The Michigan State University Agricultural Experiment Station developed a machine for testing stairway covering materials in the late 1950's. This machine which is composed of a movable table and powered by a controllable speed electric motor moves beneath a suspended portion of the machine on which is mounted a shoe half sole loaded with

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[20] Building Research Advisory, Division of Engineering and Industrial Research, Causes and Measurements of Walkway Slipperiness - Present Status and Future Needs. Federal Construction Council, Report No. 43 (Washington: National Academy of Sciences - National Research Council, 1961), p. 2.

[21] American Society for Testing Materials, "Proposed Method of Test for Measuring the Dynamic Coefficient of Friction of Waxed Floor Surfaces," ASTM Bulletin, No. 196, (February, 1954), p. 21.

[22] Bernard Berkeley and George D. Burns, "Floor Wax Slip Testing," Dura Commodities Corp. (December, 1956).

the desired amount of weight. Both the force of static and of kinetic friction can be recorded, but the machine works better for measuring the force of kinetic friction since a very low speed is required for reliable force of static friction measurements. Although this machine was not used for measuring friction on a wet surface, Dr. Esmay, the project leader, has indicated that there appears to be no reason why it would not be adequate for this purpose. This machine has also been used to obtain friction measurements of various grains--corn, wheat, oats, soy beans, etc.--on various construction materials, such as wood, concrete, tile, and others.[23]

The measuring device used by Bell Laboratories was a floor polisher which had an ammeter in its current line. When the polisher was pushed over the surface, the ammeter measured the change in current due to the increased frictional resistance of the wax film, and thus gave a direct measure of slip resistance, the results of which tended to agree well with foot appraisal and actual field experience.[24] According to the Federal Construction Council, this polisher-ammeter instrument used by Bell Laboratories (AT&T) and the Public Buildings Administration is a good instrument but justifies more research.[25]

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[23]Letter from Merle L. Esmay, Professor of Agricultural Engineering Department, Michigan State University, April 11, 1960. (Permission to quote secured.)

[24]W. H. Joy, et. al., "Symposium on Field Testing of Slip Resistance of Wax," Modern Sanitation, Vol. 3, No. 11 (November, 1951).

[25]Building Research Advisory Board, ..., op. cit., p. 23.

A friction testing machine was developed in 1961 by Dr. Henry Bowen[26] for use in testing the skid resistance of floor materials in a housing project in the School of Home Economics of the University of North Carolina at Greensboro. The components of the machine include a seven foot diameter table powered by a controllable speed electric motor set at a constant speed and a mechanical roll recorder which records friction measurements for future use in computing the force of friction.

The test results are recorded on General Electric record rolls by an ink and pen mechanism which is highly sensitive to changes in the friction between floor surface materials and heel materials. The recording instrument has to be adjusted for each test with special attention given to the positioning of the recorder pen on the zero line of the record roll.

In previous tests, 28 trapezoidal shaped test panels were mounted on a removable plywood ring and attached to the testing surface of the machine.[27]

The desired amount of weight can be stacked on the weight platform over the heel. The heel is then held stationary as the testing surface revolves underneath it at a constant speed.

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[26]Dr. Henry D. Bowen is a professor of Agricultural Engineering at North Carolina State of the University of North Carolina at Raleigh.

[27]Jean Webb Trogdon, "Skid Resistance of Waxed and Unwaxed Smooth Floor Surfaces," (Unpublished Master's thesis, The Woman's College of the University of North Carolina, Greensboro, 1962); Fern Tuten, "Testing of Skid Resistance of Smooth Floor Surfaces Using Various Sizes of Rubber and Leather Shoe Heels," (Unpublished Master's thesis, The Woman's College of the University of North Carolina, Greensboro, 1963).

Of the devices mentioned, most have been used in testing resilient floor surfaces. Only the Hunter, Sigler, and Norwegian devices have been used, according to the studies previously mentioned, for the testing of hard floor surfaces.

According to the Federal Construction Council, friction data are too closely associated with the operator's technique and the type of apparatus used to be given broad significance.[28] For the future, this report suggested that standard reference surfaces be developed and that a simple, portable, economical testing device, such as the polisher-ammeter be selected or developed.[29]

III. CONCLUSION

Although studies of skid resistance have been conducted since 1926, the studies have not established a safety code which can be applied to the slipperiness of floor surfaces. However, the Schjodt study did recommend a minimum safety value of the friction coefficient of a floor material (0.20 - 0.40) for leather soles.[30] The 1948 National Bureau of Standards' tests also indicated that a "slippery condition does or does not exist, according to whether the measured coefficient is less or greater than 0.4."[31]

Two limitations have affected the testing done in the past: (1) the range of materials, both floor and sole or heel, has been so

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[28] Building Research . . ., _loc. cit._

[29] _Ibid._, p. 3.

[30] Schjodt, _op. cit._, p. 56.

[31] Sigler, Geib, and Boone, _op. cit._, p. 346.

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[29]_Ibid_., p. 3.

[30]Schjodt, _op_. _cit_., p. 56.

[31]Sigler, Geib, and Boone, _op_. _cit_., p. 346.

limited that the results would offer no practical application for a variety of other materials commonly used by the consumer and (2) the experimental data, so closely associated with the apparatus used and the techniques of the operator, have only limited value for engineering applications unless determined under conditions reasonably simulating the requirements for each specific case.[32] In addition the polishes with new components (such as anti-skid ingredients) on the market at present, were not available when the earlier studies were conducted.

Finally, it should be noted that:

> Slipperiness measurements, although significant, may not in themselves afford an adequate basis for selecting the most satisfactory commercial floor treatment. Other factors, such as durability, appearance, ease and cost of maintenance, and the requirements of existing specifications would also need to be considered in determining the suitability of any floor finish.[33]

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[32] Building Research ..., _op_. _cit_., p. 22.

[33] Sigler, Geib, and Boone, _loc_. _cit_.

CHAPTER III

EXPERIMENTAL PROCEDURE

Since this study is a contributing part of a School of Home Economics housing project, the friction testing machine developed by Dr. Bowen and some of the procedures from that project were utilized.

This chapter includes a discussion of the selection, preparation, and testing of the hard floor surface materials (unpolished and polished) and heel materials; and the method of data analysis.

I. PREPARATION FOR TESTING

A constant room temperature ($72.5^{\circ} \pm 2.5^{\circ}$) and relative humidity ($40\% \pm 2\%$) were maintained in the laboratory throughout the testing.

The procedure used for the preparation of the hard floor surface materials was controlled somewhat by the nature and size of the materials which were used. The procedures for preparing the heel materials and for the testing of the floor and heel materials were based upon previous testing of the skid resistances of resilient floor surfaces.[1]

Selection and Preparation of the Floor Surface Materials

Seven different locally available hard floor surface materials were selected. The materials were: aggregate, ceramic tile (unglazed),

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[1] Trogdon, op. cit.

ceramic tile (glazed), ceramic tile in vinyl or rubber base, concrete, quarry tile and terrazzo. Four samples of each of the floor surface materials, two samples from each of two companies, were secured. The concrete and aggregate samples were poured, by the supplying company, into trapezoidal shaped molds. The concrete samples were coated with a sealer provided by one of the concrete companies to prevent powdering.

The ceramic tile in a vinyl base and in a rubber base, and the terrazzo samples were cut into trapezoids by a local masonry company. The quarry and ceramic tiles in a mortar base were cut and set into the desired shape by a tile setter.

The hard floor surface samples were of varying thicknesses. In order to secure an even testing surface among the flooring samples, the samples were mounted on different thicknesses of plywood so that each would equal the height of the thickest sample which was the seven-eights inch terrazzo. The 28 test samples were cemented to a plywood ring. The joints within and between the test panels were filled with a white tile grout which was applied by a tile setter. These joints were also coated with the sealer so that the heels would not accumulate any powdery residue from the grout.

Selection and Preparation of the Heel Materials

Five types of materials were acquired from and mounted by a local shoe repairer who was able to supply two brands for each material. The heel materials used in the study were leather, Neolite, nylon, rubber and rubber crepe.

Before the heel materials were used for testing they were cut to a square inch and the face finishes were worn off by running the heels over No. 400A corborundum paper attached to the surface of the friction testing machine. The purpose of this procedure was to make it possible for the entire inch square area of heel surface to come in contact with the floor materials.

The Selection of Polishes

One brand from each of three kinds of water emulsion polish; standard, clear, and skid resistant; was selected for use in this study. The particular brand of standard polish was chosen because it was found to be the most widely sold polish in this locale;[2] the clear because it was commonly used and readily available and the skid resistant because it was the only one of its kind found on the grocery store shelves in the local area.

Choice of Weight Loads

The 25 pound weight load chosen for this study was based upon the results of a study of the pressures on the human foot in walking.[3] Results of this study revealed that there was a poor correlation (.35) between a person's weight and the amount of pressure exerted by the heel on the floor during walking. It was also found that the maximum pressure exerted by most of the subjects in the study ranged between 20 and 30 pounds with an average of 25 pounds per square inch; but for all subjects tested, the pressures ranged from seven to 45 pounds per square inch.[4]

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[2] Janice C. Penn, "Appraisal of Gloss and Slipperiness of Resilient Floor Covering Materials" (unpublished Master's thesis, The Woman's College of the University of North Carolina, Greensboro, June, 1963), p. 24.

[3] "Pressures on the Human Foot During Walking," Australian Journal of Applied Science, Vol. 3, 1953, p. 411.

[4] Ibid., pp. 411, 416.

II. TESTING PROCEDURE

Order of Testing

A randomized block design was used to determine the position of each of the 28 hard floor surface samples on the testing machine. The 28 test panels were divided into two equal blocks constituting two samples of each of the seven floor materials, one sample from each manufacturer (Table I).

The hard floor surface materials were tested in the dry and wet unpolished conditions and in polished conditions dry and with moisture applied. The unpolished conditions were composed of the new hard floor surface materials and the hard floor surface materials after accelerated wear. The floor surfaces were worn by sanding with No. 400A carborundum paper attached to a sanding block which was attached to the weight platform of the testing machine. The testing surface was revolved 20 times beneath the block since a previous study indicated the leveling off of the coefficient of friction after 15 - 20 repetitive tests.[5]

The ten heel samples, two companies for each of the five different types were numbered randomly for the first 40 tests. These tests were comprised of the new unpolished tests (1-20) and the worn unpolished tests (21-40), both dry and wet (Table II). For tests 41 through 85 the heels were grouped by type and each type was randomly assigned in testing order. All ten heels were used in the dry polished

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[5] Michigan Contributing Project Report for 1959, Agricultural Engineering Department, Michigan State University, p. 2. (Mimeographed).

Table 1

FLOOR MATERIALS BY MANUFACTURER

AND

POSITION ON THE TESTING SURFACE

Floor materials	Manufacturer	Test panel number	
		Block I	Block II
Aggregate	J. C. Canaday Co.	1	25
	Weimar Products, Inc.	9	22
Ceramic unglazed	United States Ceramic Tile Company	2	24
	American Olean Tile Co.	12	16
Ceramic in vinyl	Stylon Corporation	3	18
Ceramic in rubber	United States Ceramic Tile Company	5	26
Cement	Ready-Mix Concrete Co.	4	15
	F. D. Lewis and Son, Inc.	13	23
Ceramic glazed	American Olean Tile Co.	6	19
	Stylon Corporation	11	17
Terrazzo	Marus Marble & Tile Co.	7	27
	Ward Tile Company	10	21
Quarry tile	Mosaic Tile Company	8	28
	Murray Tile Co.	14	20

TABLE II

HEEL MATERIALS BY MANUFACTURER AND ORDER OF TESTING

Heel materials	Manufacturer	Order of testing heels 1-40	Unpolished floors				Order of testing heels 41-85	Polished floors					
			New 1-20		Worn 21-40			Clear 41-55		Standard 56-70		Skid resistant 71-85	
			dry	wet	dry	wet		dry	wet	dry	wet	dry	wet
						(Test numbers)							
Neolite	Goodyear	1	1	11	21	31	4	44		59		74	
	Goodyear	2	2	12	22	32	3	43	52	58	67	73	82
Nylon	Catspaw	3	3	13	23	33	1	41	51	56	66	71	81
	Goodyear	8	8	18	28	38	2	42		57		72	
Rubber	Goodrich	4	4	14	24	34	7	47	54	62	69	77	84
	Seiberling	7	7	17	27	37	8	48		63		78	
Leather	Galco	5	5	15	25	35	5	45	53	60	68	75	83
	G. W. Hill	6	6	16	26	36	6	46		61		76	
Rubber crepe	Catspaw	9	9	19	29	39	9	49	55	64	70	79	85
	Avon	10	10	20	30	40	10	50		65		80	

testing but only one revolution was made for each heel in order to limit the wear of the polishes. The first heel of a group type (1, 3, 5, 7, 9) was used in the polished testing with each of the five heels making two revolutions.

A system was devised for designating tracks for the ten shoe heel materials. All of the heels in the first 40 tests were run in two tracks. One track was three inches from the outside edge of the testing surface and the other was three inches from the inside edge. For the polish tests five tracks were used with the first track two inches from the outside of the testing surface and the last track two inches from the inside of the testing surface. Both brands of a heel material in the polish tests were run in a specific track.

The hard floor surface materials were tested dry and with moisture applied for the new, worn, and three polished conditions. The three kinds of polish (standard, clear, and skid resistant) were tested in random order. Moisture was applied to the floor materials by means of a spray atomizer.

The Application and Removal of Polishes

The procedure used for polish application was a modification of the one recommended in the ASTM Designation No. 31436.[6] Applicator pads were made of No. 50 grade cheesecloth cut into two-inch strips weighing 0.60 grams each. The area of the trapezoid was determined

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[6]"Tentative Methods for Application of Emulsion Floor Polishes to Substrates for Testing Purposes," American Society for Testing Materials, ASTM Designation: D 1436 - 56 T (Reprinted from Copyrighted 1956 Supplement to Book of ASTM Standards, Part 4), pp. 112, 113.

and the volume of polish, (.1 ml. of polish for each 4 square inches) was calculated for this area.[7] The required amount of polish (1.7 ml.)[8] was pipetted into the middle of a cheesecloth applicator pad and was distributed evenly over the surface of the test panel. As soon as the polish had been applied, the applicator pad was placed in a ground-glass stoppered weighing bottle and weighed in order to calculate and record the net weight of the used wet applicator.

The weight of the spent applicators could not vary by more than 0.15 grams since a constant film thickness was desired. If the weight variation exceeded 0.15 grams, the test panel was cleaned and repolished. The coated surfaces were then allowed to dry overnight.[9]

The test panels were cleaned, or stripped of the polish, with a solution of one part detergent and one part ammonia to six parts of water. This solution was applied with a sponge to the floor materials and allowed to stand a few minutes. The floor materials were scrubbed with a piece of steel wool, rinsed, and then thoroughly dried.

Calibration Readings

Calibration readings were recorded before and after each heel tested. These readings provided the means by which the test readings could be converted into pounds of frictional force. The amount of frictional force anticipated in a test determined the number of pounds of weight used in a calibration. A total of 26 pounds was used.

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[7] *Ibid.*

[8] Penn, *op. cit.* p. 26.

[9] "Tentative Methods for Application...", *op. cit.*

The calibration procedure consisted of lifting the test heel one-sixteenth of an inch above the testing surface, adding the 26 pounds of weight - two pounds at a time - to the nylon cord attached to the heel, and removing the weights two pounds at a time. The readings were recorded and averaged. The means were plotted on a graph and a line, drawn between the points, was used to read the force of friction values.

Method of Data Collection

Two determinations, or two complete revolutions of the testing surface on the friction testing apparatus, were made for each of the heels in the first 40 tests. In order to limit the wear of the polishes, only one revolution was made for each of the ten heels in the dry, polished tests.

Two revolutions were made for each of the five heels for the polished tests with moisture applied. Only one heel was run in each of the five tracks because it was assumed that there would be some accumulation of residue from the heel and dissolved polish. When there were two determinations, a mean was derived and read from the calibration graph as the amount of force in pounds required to overcome friction between a certain heel material and a given floor surface material. Where there was only one determination for heel materials, the force was read using that one determination in the same way as the mean was used in the other tests.

Treatment of the Data

Standard analysis of variance techniques were utilized in the treatment of the data. The composition of the analyses of variance were formulated by Dr. Robert Hadar.[10] The data were analyzed by means of a computer at the computation center, North Carolina State.

Separate analysis of variance were used to test (1) dry unpolished and polished floor materials, (2) new and worn floor materials with moisture applied, and (3) polished floor materials with moisture applied. The analysis of the new and worn conditions with moisture applied were separated from the polished conditions with moisture applied because of the lack of heel duplication. This separation simplified the statistical analysis.

Because of the nature of the experimental model, it was necessary in some cases to use Satterwaite's approximate test procedure[11] to determine the significance of some of the variance components.

All values used in the analysis of variance computations were force of friction values. The original plan included printing of the force of friction means by the computer for only those sources of variation which were considered important to this study. Coefficient of friction values were obtained from the printed force of friction means for the majority of the sources of variation from the separate analyses which were significant at the one per cent level of probability.

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[10]Dr. Hadar is a statistician with the Department of Experimental Statistics, North Carolina State of the University of North Carolina at Raleigh.

[11]Bernard Ostle, Statistics in Research, (Ames, Iowa: The Iowa State University Press, 1963), pp. 302-303.

CHAPTER IV

EXPERIMENTAL RESULTS

The results of this study of the skid resistance of hard floor surface materials will be presented and discussed in three parts as follows: (1) dry, unpolished and polished hard floor surface materials, (2) new and worn (unpolished) hard floor surface materials with moisture applied, and (3) polished hard floor surface materials with moisture applied.

I. DRY, UNPOLISHED AND POLISHED HARD FLOOR SURFACE MATERIALS

Floor Materials

Analysis of the data (Table I, Appendix B) revealed highly significant differences ($P \leq 0.001$) between the force of friction values obtained on the dry floor materials. The overall coefficient of friction values for the seven floor materials are presented in Table III. It would appear that the differences in coefficient of friction do not vary significantly among quarry tile, ceramic unglazed and ceramic in vinyl or rubber or between concrete and glazed ceramic.

The differences in coefficients of friction between the duplicate samples within manufacturers of floor materials were significant even though the differences between the manufacturers of floor materials were not significant. When manufacturers within floor materials were compared with the duplicate samples from manufacturers of floor

TABLE III

COEFFICIENTS OF FRICTION OF SEVEN DRY UNPOLISHED AND POLISHED HARD FLOOR SURFACE MATERIALS BY MANUFACTURER

Floor material	Manufacturer[1] 1	2	Overall mean
Terrazzo	.608	.608	.608
Quarry tile	.615	.644	.629
Ceramic unglazed	.647	.630	.638
Ceramic in vinyl or rubber	.651	.653	.652
Concrete	.681	.687	.684
Ceramic glazed	.698	.681	.689
Aggregate	.708	.744	.726

[1]Each value is the mean for 94 measurements.

materials, (Table IV), it was evident that there was little difference in the coefficients of friction between the duplicate samples from each manufacturer and between those of the two manufacturers.

Heel Materials

There were significant differences ($P \leq .01$) between the five heel materials. The overall mean coefficient of friction values for the five heel materials tested with the dry floor materials are found in Table V.

It would appear that there was a significant difference in the coefficients of friction between each heel material with the possible exception of nylon and rubber.

There were highly significant differences among the duplicate samples representing two manufacturers within heel materials. Coefficients of friction presented in Table V show that there was a greater difference between heel materials than between duplicate samples within heel materials.

Floor Materials by Heel Materials.

Although there was no significant interaction between floor and heel materials, it was interesting to note in Table VI the consistent increase in the coefficient of friction values for the heel materials, the increase always being from leather to rubber crepe. The range in overall mean coefficients of friction was five times greater for heel materials than for floor materials.

For all floor and heel material interactions, the leather heel material had the lowest coefficient of friction value for all the dry

TABLE IV

COEFFICIENTS OF FRICTION OF SEVEN DRY UNPOLISHED

AND POLISHED FLOOR MATERIALS BY DUPLICATES WITHIN MANUFACTURERS

Floor material	Manufacturer 1		Manufacturer 2	
	Duplicate[1] 1	Duplicate[1] 2	Duplicate[1] 1	Duplicate[1] 2
Terrazzo	.602	.614	.571	.645
Quarry tile	.609	.620	.622	.667
Ceramic unglazed	.640	.653	.621	.639
Ceramic in vinyl or rubber	.660	.643	.665	.641
Concrete	.686	.677	.686	.689
Ceramic glazed	.685	.711	.652	.709
Aggregate	.699	.717	.722	.767

[1] Each value is the mean for 47 measurements.

TABLE V

COEFFICIENTS OF FRICTION OF DUPLICATE HEEL MATERIALS TESTED WITH VARIOUS DRY UNPOLISHED AND POLISHED HARD FLOOR SURFACE MATERIALS

Heel material	Duplicates 1	Duplicates 2	Overall mean
Leather[1]	.328	.328	.328
Nylon[1]	.630	.591	.610
Rubber[1]	.591	.705	.648
Neolite[2]	.769	.796	.783
Rubber crepe[2]	.862	1.010	.936

[1]Each value is the mean for 112 measurements.

[2]Each value is the mean for 140 measurements.

TABLE VI

COEFFICIENTS OF FRICTION OF SEVEN DRY UNPOLISHED AND POLISHED HARD FLOOR SURFACE MATERIALS BY VARIOUS HEEL MATERIALS

Floor material	Heel material					Overall average
	Leather[1]	Nylon[1]	Rubber[1]	Neolite[2]	Rubber crepe[2]	
Terrazzo	.297	.550	.593	.742	.857	.608
Quarry tile	.346	.581	.627	.731	.863	.629
Ceramic unglazed	.342	.591	.629	.727	.901	.638
Ceramic in vinyl or rubber	.315	.599	.638	.760	.948	.652
Cement	.356	.631	.671	.802	.961	.684
Ceramic glazed	.299	.641	.679	.846	.981	.689
Aggregate	.341	.679	.699	.870	1.042	.726
Overall average	.328	.610	.648	.783	.936	

[1]Each value is the mean for 36 measurements.

[2]Each value is the mean for 40 measurements.

hard floor surface materials. Rubber crepe had the highest coefficient of friction values for the dry hard floor materials.

Floor Surface Conditions by Heel Materials

There was a significant floor condition by heel material interaction ($P \leq .01$). This was probably due in part to the fact that coefficients of friction were lowest for the floor materials with a skid resistant polish when tested with leather and nylon and highest when tested with Neolite and rubber crepe (Table VII).

In general, the lowest coefficients of friction were associated with the dry polished floor materials. The coefficients of friction between rubber crepe and the dry polished floor materials were, however, the highest observed in this phase of the study.

Condition, Heel and Floor Materials

Although the interaction between these three main factors was not found to be significant, three definite patterns were apparent in coefficients of friction (Table VIII). These patterns were:

1. For leather heels, the coefficient of friction was lowest for all dry hard floor surface materials with the skid resistant polish. This was also true for nylon and rubber heels for over half of the hard floor surface materials.

2. For rubber crepe heels the coefficient of friction was highest for all dry hard floor surface materials with skid resistant polish applied. This was also true for Neolite for over half of the dry hard floor surface materials.

3. For leather, nylon, and rubber heels the coefficients of friction were higher for most dry hard floor surface materials with the standard polish than with the clear or skid resistant polishes.

TABLE VII

COEFFICIENTS OF FRICTION OF SEVEN DRY, HARD FLOOR SURFACE MATERIALS IN UNPOLISHED AND POLISHED CONDITIONS BY HEEL MATERIALS

Condition of floor materials	Heel material[1]					Overall average
	Leather	Nylon	Rubber	Neolite	Rubber crepe	
Unpolished						
New	.405	.665	.630	.794	.880	.675
Worn	.354	.682	.710	.797	.885	.686
Polished						
Clear	.301	.590	.609	.734	.910	.629
Standard	.329	.601	.670	.784	.918	.660
Skid resistant	.252	.515	.622	.804	1.087	.656
Overall average for heel materials	.328	.610	.648	.783	.936	

[1]Each value for the new condition by the leather, nylon, and rubber heels is the mean for 28 measurements. Each of the remaining values is the mean for 56 measurements.

TABLE VIII

COEFFICIENTS OF FRICTION OF SEVEN UNPOLISHED AND POLISHED DRY, HARD FLOOR SURFACE MATERIALS BY VARIOUS HEEL MATERIALS

Floor material	Condition	Heel material[1] Leather	Nylon	Rubber	Neolite	Rubber crepe	Overall average
Terrazzo	Unpolished						
	New	.279	.542	.523	.741	.769	.571
	Worn	.260	.558	.604	.727	.779	.586
	Polished						
	Clear	.304	.596	.596	.733	.864	.618
	Standard	.393	.581	.639	.725	.875	.642
	Skid resistant	.247	.475	.604	.783	.998	.621
Quarry tile	Unpolished						
	New	.468	.682	.657	.766	.853	.685
	Worn	.352	.664	.698	.771	.839	.664
	Polished						
	Clear	.344	.528	.573	.671	.800	.583
	Standard	.304	.613	.664	.757	.869	.642
	Skid resistant	.262	.420	.544	.689	.952	.573
Ceramic unglazed	Unpolished						
	New	.444	.678	.645	.753	.872	.679
	Worn	.387	.671	.682	.763	.870	.674
	Polished						
	Clear	.310	.554	.598	.673	.885	.604
	Standard	.307	.602	.674	.752	.861	.639
	Skid resistant	.263	.451	.548	.697	1.016	.595
Ceramic in vinyl or rubber	Unpolished						
	New	.395	.643	.629	.763	.864	.659
	Worn	.348	.693	.700	.785	.874	.680
	Polished						
	Clear	.297	.569	.600	.704	.939	.622
	Standard	.292	.628	.684	.810	.977	.678
	Skid resistant	.245	.464	.577	.738	1.085	.622
Concrete	Unpolished						
	New	.462	.696	.658	.813	.939	.714
	Worn	.430	.697	.713	.799	.901	.708
	Polished						
	Clear	.294	.600	.646	.740	.893	.635
	Standard	.346	.603	.671	.797	.939	.671
	Skid resistant	.249	.562	.668	.861	1.132	.694

[1]Each value for the new condition on all floor materials by the leather, nylon, and rubber heels is the mean for four measurements. Each of the remaining values is the mean for eight measurements.

(Table VIII continued)

Floor material	Condition	Heel material[1] Leather	Nylon	Rubber	Neolite	Rubber crepe	Overall average
Ceramic glazed	Unpolished						
	New	.335	.706	.633	.855	.937	.693
	Worn	.305	.741	.786	.854	.917	.721
	Polished						
	Clear	.275	.589	.596	.767	.896	.625
	Standard	.351	.623	.715	.853	.953	.699
	Skid resistant	.231	.548	.664	.902	1.202	.709
Aggregate	Unpolished						
	New	.454	.708	.663	.869	.925	.724
	Worn	.398	.752	.789	.878	1.018	.767
	Polished						
	Clear	.281	.695	.652	.849	1.090	.713
	Standard	.309	.557	.640	.796	.951	.651
	Skid resistant	.265	.683	.748	.957	1.223	.775

Conditions by Manufacturer Within Floor Materials

The interaction between condition and the manufacturers within floor materials was significant. However, there was no apparent explanation for this significant interaction other than the differences in coefficient of friction between the two manufacturers of the aggregate floor surfaces with the skid resistant and standard polish and the quarry tile in the new condition (Table IX).

Condition by Duplicates Within Manufacturers Within Floor Materials

The interaction between condition and the duplicates within manufacturers within floor materials was significant ($P \leq 0.01$). This can be explained in part by the differences in coefficients of friction between: duplicates of manufacturer two of terrazzo and glazed ceramic, unpolished (new and worn) and with standard polish; between duplicates of manufacturer one of worn glazed ceramic; between duplicates of manufacturer one for new and clear polished aggregate; and between duplicates of manufacturer two for clear and standard polished aggregates.

II. UNPOLISHED HARD FLOOR SURFACE MATERIALS WITH MOISTURE APPLIED

Floor Materials

Analysis of the data (Table II, Appendix B) revealed significant differences ($P \leq .01$) between the forces of friction of the floor materials. The overall coefficient of friction values for the seven floor materials with moisture applied are presented in Table XI. Apparently the coefficients of friction of wet glazed ceramic and quarry tile were significantly different from all of the other floor materials. However,

TABLE IX

COEFFICIENTS OF FRICTION OF SEVEN HARD FLOOR SURFACE MATERIALS BY MANUFACTURER AND BY DRY, UNPOLISHED AND POLISHED CONDITIONS

Floor material	Manu-facturer	Conditions[1]				
		Unpolished		Polished		
		New	Worn	Clear	Standard	Skid resistant
Terrazzo	1	.553	.602	.630	.625	.629
	2	.589	.570	.608	.661	.614
Quarry tile	1	.634	.641	.582	.643	.574
	2	.737	.688	.585	.640	.573
Ceramic unglazed	1	.672	.695	.627	.652	.589
	2	.685	.655	.581	.627	.602
Ceramic in vinyl or rubber	1	.685	.694	.605	.680	.593
	2	.633	.667	.639	.676	.651
Concrete	1	.689	.704	.632	.691	.692
	2	.738	.713	.638	.652	.697
Ceramic glazed	1	.682	.742	.636	.732	.699
	2	.705	.700	.613	.666	.720
Aggregate	1	.695	.742	.718	.690	.694
	2	.753	.792	.708	.612	.858

[1]Each value for all manufacturers within floor materials by the new condition is the mean for 14 measurements. Each of the remaining values is the mean for 20 measurements.

TABLE X

COEFFICIENTS OF FRICTION OF DUPLICATE DRY, HARD FLOOR SURFACE MATERIALS WITHIN MANUFACTURERS BY UNPOLISHED AND POLISHED CONDITIONS

Floor material	Manu-facturer	Duplicates within manu-facturer	Conditions[1]				
			Unpolished		Polished		
			New	Worn	Clear	Standard	Skid resistant
Terrazzo	1	1	.532	.569	.625	.641	.641
		2	.574	.635	.635	.608	.617
	2	1	.533	.517	.585	.606	.612
		2	.644	.622	.630	.715	.615
Quarry tile	1	1	.634	.623	.578	.634	.574
		2	.633	.658	.586	.652	.573
	2	1	.711	.654	.566	.608	.570
		2	.762	.722	.604	.671	.575
Ceramic un-glazed	1	1	.638	.676	.656	.637	.594
		2	.706	.713	.597	.667	.583
	2	1	.633	.645	.581	.608	.607
		2	.707	.664	.581	.645	.596
Ceramic in vinyl or rubber	1	1	.670	.687	.649	.679	.613
		2	.700	.701	.561	.681	.573
	2	1	.623	.652	.673	.701	.676
		2	.643	.681	.604	.651	.625

[1]Each value for all duplicates within manufacturers within floor materials by the new condition is the mean for seven measurements. Each of the remaining values is the mean for ten measurements.

Table X (continued)

Floor material	Manu-facturer	Duplicates within manu-facturer	Conditions[1]				
			Unpolished		Polished		
			New	Worn	Clear	Standard	Skid resistant
Concrete	1	1	.648	.707	.668	.722	.683
		2	.730	.700	.595	.659	.701
	2	1	.743	.721	.637	.627	.700
		2	.733	.704	.638	.677	.693
Ceramic glazed	1	1	.653	.698	.642	.717	.713
		2	.710	.785	.630	.746	.685
	2	1	.662	.663	.595	.626	.716
		2	.747	.737	.631	.706	.723
Aggregate	1	1	.656	.730	.756	.677	.674
		2	.734	.754	.680	.702	.713
	2	1	.732	.773	.668	.577	.858
		2	.773	.810	.748	.647	.857

TABLE XI

COEFFICIENTS OF FRICTION OF WET, NEW AND WORN UNPOLISHED HARD FLOOR SURFACE MATERIALS BY VARIOUS HEEL MATERIALS

Floor materials	Heel materials[1]					Overall mean
	Leather	Nylon	Rubber	Neolite	Rubber crepe	
Ceramic glazed	.151	.370	.371	.268	.255	.283
Concrete	.259	.539	.565	.659	.688	.542
Aggregate	.191	.544	.556	.668	.774	.547
Terrazzo	.264	.540	.586	.699	.697	.557
Ceramic in vinyl or rubber	.342	.591	.608	.669	.683	.579
Ceramic unglazed	.367	.608	.623	.674	.679	.590
Quarry tile	.480	.640	.665	.723	.694	.640
Average	.294	.547	.568	.623	.639	

[1]Each value is the mean for 16 measurements.

insignificant differences in coefficient of friction were noted between concrete, aggregate and terrazzo and between ceramic unglazed and ceramic in vinyl or rubber.

The differences in coefficients of friction among the duplicate samples from manufacturers of floor materials were highly significant ($P \leq .001$) even though the differences among the manufacturers of floor materials were not significant (Table XII).

The coefficients of friction were higher for the second duplicate than for the first duplicate for all of the floor materials except the aggregate from manufacturer one. No consistent pattern was noted between the coefficients of friction for the two manufacturers.

Heel Materials

There were highly significant differences ($P \leq .001$) between the five heel materials. Only the coefficients of friction of leather appeared to be significantly different from all of the other heel materials (Table XI). Coefficient of friction values for nylon and rubber and for Neolite and rubber crepe were essentially the same.

There were also highly significant differences among the duplicate samples within heel materials. However, from coefficient of friction Table XI it was shown that there was a greater difference between heel materials than between duplicate samples within heel materials (Table XIII).

Floor Materials by Heel Materials

Analysis of the data revealed a significant wet floor material by heel material interaction ($P \leq .01$) and the range in overall coefficients of friction was very similar for both materials. There was a consistent

TABLE XII

COEFFICIENTS OF FRICTION OF WET NEW AND WORN UNPOLISHED HARD FLOOR SURFACE MATERIALS BY DUPLICATE MANUFACTURERS

Floor materials[1]	Manufacturer 1 Duplicates 1	Manufacturer 1 Duplicates 2	Mean for manufacturer 1	Manufacturer 2 Duplicates 1	Manufacturer 2 Duplicates 2	Mean for manufacturer 2
Ceramic glazed	.269	.274	.272	.272	.318	.295
Concrete	.465	.551	.508	.539	.615	.577
Aggregate	.541	.529	.535	.531	.587	.559
Terrazzo	.490	.531	.511	.589	.619	.604
Ceramic in vinyl or rubber	.614	.640	.627	.510	.552	.531
Ceramic unglazed	.592	.652	.622	.543	.575	.559
Quarry tile	.602	.631	.617	.637	.692	.665

[1]Each value is the mean for 20 measurements.

TABLE XIII

COEFFICIENTS OF FRICTION OF DUPLICATE HEEL MATERIALS TESTED WITH VARIOUS NEW AND WORN UNPOLISHED, HARD FLOOR SURFACE MATERIALS WITH MOISTURE APPLIED

Heel material[1]	Duplicate 1	Duplicate 2
Leather	.272	.315
Nylon	.545	.550
Rubber	.551	.584
Neolite	.599	.647
Rubber crepe	.689	.588

[1]Each value is the mean for 56 measurements.

increase in coefficient of friction values for new and worn concrete, aggregate, ceramic in vinyl or rubber, and unglazed ceramic with moisture applied (Table XI).

The leather heel had the lowest coefficient of friction value for the wet new and worn (unpolished) hard floor surface materials. Rubber crepe had the highest coefficient of friction values for four of the seven wet new and worn (unpolished) hard floor surface materials. The three other highest coefficient of friction values for wet unpolished floor materials were for Neolite with terrazzo and quarry tile and the rubber heel with glazed ceramic.

Condition, Heel and Floor Materials

Although the interaction among these three main factors was not found to be significant, two definite patterns were apparent in coefficient of friction Table XIV:

1. The coefficient of friction of all the floor materials was higher in the new condition than in the worn condition for leather heels.

   The coefficient of friction of over half of the floor materials was higher in the new condition than in the worn condition for the rubber and rubber crepe heels.

2. In contrast, the coefficient of friction for over half of the floor materials was higher in the worn condition with the nylon and Neolite heels.

III. POLISHED HARD FLOOR SURFACE MATERIALS WITH MOISTURE APPLIED

Floor Materials

The differences in force of friction values between polished floor materials with applied moisture were highly significant ($P \leq .001$ in Table III, Appendix B). The overall coefficient of friction values for

TABLE XIV

COEFFICIENTS OF FRICTION OF UNPOLISHED AND POLISHED HARD FLOOR SURFACE MATERIALS WITH MOISTURE APPLIED BY VARIOUS HEEL MATERIALS

Floor material	Condition of floor	Heel material[1]					Overall average
		Leather	Nylon	Rubber	Neolite	Rubber crepe	
Ceramic glazed	Unpolished						
	New	.166	.370	.389	.281	.265	.294
	Worn	.136	.370	.354	.255	.245	.272
	Polished						
	Clear	.119	.258	.340	.311	.363	.278
	Standard	.171	.245	.363	.318	.337	.287
	Skid resistant	.193	.171	.253	.286	.411	.263
Concrete	Unpolished						
	New	.280	.526	.563	.620	.691	.536
	Worn	.238	.551	.567	.699	.686	.548
	Polished						
	Clear	.181	.491	.442	.625	.553	.458
	Standard	.282	.612	.593	.564	.546	.519
	Skid resistant	.221	.224	.309	.312	.446	.302
Aggregate	Unpolished						
	New	.206	.540	.580	.646	.796	.554
	Worn	.176	.549	.533	.691	.751	.540
	Polished						
	Clear	.131	.429	.414	.441	.566	.396
	Standard	.175	.599	.543	.537	.549	.481
	Skid resistant	.152	.229	.309	.296	.458	.289
Terrazzo	Unpolished						
	New	.293	.527	.574	.663	.684	.548
	Worn	.234	.553	.597	.735	.710	.566

[1]Each value for all the unpolished floor materials by all the heels is the mean for eight measurements. Each value for all the polished floor materials by all the heels is the mean for four measurements.

Table XIV (continued)

Floor material	Condition of floor	Heel material[1]					Overall average
		Leather	Nylon	Rubber	Neolite	Rubber crepe	
Terrazzo (continued)	Polished						
	Clear	.102	.522	.455	.643	.541	.393
	Standard	.242	.586	.594	.602	.565	.518
	Skid resistant	.213	.307	.364	.408	.476	.354
Ceramic in vinyl or rubber	Unpolished						
	New	.359	.590	.613	.668	.683	.583
	Worn	.325	.593	.602	.671	.684	.575
	Polished						
	Clear	.242	.426	.496	.587	.617	.474
	Standard	.323	.562	.587	.605	.625	.540
	Skid resistant	.297	.309	.441	.428	.533	.402
Ceramic unglazed	Unpolished						
	New	.397	.610	.633	.674	.680	.599
	Worn	.338	.606	.614	.674	.678	.582
	Polished						
	Clear	.260	.508	.553	.599	.638	.512
	Standard	.315	.559	.612	.615	.597	.540
	Skid resistant	.307	.343	.482	.436	.548	.423
Quarry tile	Unpolished						
	New	.494	.641	.659	.716	.694	.641
	Worn	.466	.638	.671	.729	.694	.640
	Polished						
	Clear	.361	.510	.546	.716	.602	.547
	Standard	.466	.591	.583	.740	.608	.598
	Skid resistant	.419	.365	.498	.470	.540	.458

the seven polished floor materials with moisture applied are presented in Table XV. The coefficient of friction of glazed ceramic, aggregate and quarry tile appear to be significantly different from those of the other floor materials. The coefficients of friction of glazed ceramic and aggregate were lower and the coefficients of friction of quarry tile were higher than those of the other materials. The coefficients of friction do not appear to be significantly different between concrete and terrazzo and between ceramic unglazed and in vinyl or rubber.

The differences among manufacturers within floor materials was also highly significant ($P \leq .001$), with the greatest difference between the manufacturers of the ceramic tile in vinyl or rubber. This difference was not surprising since these floor materials - one in vinyl and one in rubber - were not identical.

Heel Materials

There were highly significant differences ($P \leq .001$) among the five heel materials. The overall coefficient of friction values for the five heel materials tested with polished hard floor surface materials with moisture applied are presented in Table XV. The coefficients of friction for leather and possibly nylon and rubber appear to be significantly different from the other heel materials.

Floor Materials by Heel Materials

There was a highly significant floor by heel interaction ($P \leq .001$) with moisture applied and the range in overall mean coefficients of friction was very similar for both materials (Table XV). There was a consistent increase in the coefficient of friction values for polished

TABLE XV

COEFFICIENTS OF FRICTION OF POLISHED, HARD FLOOR SURFACE MATERIALS WITH MOISTURE APPLIED BY VARIOUS HEEL MATERIALS

Floor materials	Heel materials[1]					Overall mean
	Leather	Nylon	Rubber	Neolite	Rubber crepe	
Ceramic glazed	.161	.225	.318	.305	.370	.276
Concrete	.228	.442	.448	.501	.515	.427
Aggregate	.153	.419	.422	.425	.524	.388
Terrazzo	.186	.472	.471	.551	.527	.441
Ceramic in vinyl or rubber	.287	.432	.508	.540	.592	.472
Ceramic unglazed	.294	.470	.549	.550	.594	.491
Quarry tile	.415	.489	.542	.642	.583	.534
Overall average	.246	.421	.502	.465	.529	

[1]Each value is the mean for 12 measurements.

concrete, aggregate, ceramic in vinyl or rubber and unglazed ceramic with moisture applied for all of the heel materials.

Floor Surface Condition

Analysis of the data revealed that the differences among floor conditions were not significant. However, the coefficients of friction in Table XVI did show a difference between the skid resistant polish and the clear and standard polishes. Therefore, individual degrees of freedom were calculated and the skid resistant polish was found to be significantly different from the clear and standard polishes (Table III, Appendix B).

Floor Surface Condition by Floor Materials

Analysis of the data indicated highly significant condition by floor material interaction ($P \leq .001$) with moisture applied. For all hard floor surface materials coefficients of friction were highest for the standard polish and lowest for the skid resistant polish (Table XVII).

Floor Surface Condition by Heel Materials

There was a highly significant floor surface condition by heel material interaction ($P \leq .001$) with moisture applied. For all heel materials except leather, the coefficients of friction were lowest for the skid resistant polish. For the leather heel the coefficient of friction was lowest with the clear polish (Table XVIII).

For leather, nylon, Neolite, and rubber heels, the coefficients of friction were highest for the standard polish with moisture applied. However, for the rubber crepe heel the coefficient of friction was

TABLE XVI

COEFFICIENTS OF FRICTION OF UNPOLISHED AND POLISHED HARD FLOOR SURFACE MATERIALS WITH MOISTURE APPLIED BY MANUFACTURERS

Floor material[1]	Unpolished			Polished		
	Manu-facturer one	Manu-facturer two	Aver-age	Manu-facturer one	Manu-facturer two	Aver-age
Ceramic glazed	.271	.295	.283	.265	.287	.276
Concrete	.508	.577	.542	.396	.457	.427
Aggregate	.535	.559	.547	.398	.379	.388
Terrazzo	.511	.604	.557	.429	.454	.441
Ceramic in vinyl or rubber	.627	.531	.579	.518	.426	.472
Ceramic unglazed	.622	.558	.590	.520	.462	.491
Quarry tile	.616	.664	.640	.532	.537	.534

[1]Each value for the unpolished floor materials by the manufacturers is the mean for 40 measurements. Each value for the polished floor materials by the manufacturers is the mean for 30 measurements.

TABLE XVII

COEFFICIENTS OF FRICTION OF HARD FLOOR SURFACE MATERIALS BY UNPOLISHED AND POLISHED CONDITIONS WITH APPLIED MOISTURE

Floor material[1]	Condition				
	Unpolished		Polished		
	New	Worn	Clear	Standard	Skid resistant
Ceramic glazed	.294	.272	.278	.287	.263
Concrete	.536	.548	.458	.519	.302
Aggregate	.554	.540	.396	.481	.289
Terrazzo	.548	.566	.393	.518	.354
Ceramic in vinyl or rubber	.583	.575	.474	.540	.402
Ceramic unglazed	.599	.582	.512	.540	.423
Quarry tile	.641	.640	.547	.598	.458
Overall average	.536	.532	.445	.497	.356

[1]Each value for the unpolished floor materials is the mean for 40 measurements. Each value for the polished floor materials is the mean for 20 measurements.

TABLE XVIII

COEFFICIENTS OF FRICTION OF HARD FLOOR SURFACE MATERIALS IN UNPOLISHED AND POLISHED CONDITIONS, WITH MOISTURE APPLIED, BY HEEL MATERIALS

Conditions of floor material[1]	Heel materials					Overall average
	Leather	Nylon	Rubber	Neolite	Rubber crepe	
Unpolished						
New	.314	.543	.573	.610	.642	.536
Worn	.273	.551	.563	.636	.635	.532
Polished						
Clear	.199	.449	.464	.560	.554	.445
Standard	.282	.536	.554	.569	.547	.497
Skid resistant	.257	.278	.379	.377	.487	.356

[1] Each value for the unpolished floor materials by the heel materials is the mean of 56 measurements. Each value for the polished floor materials by the heel materials is the mean of 28 measurements.

highest with the clear polish with moisture applied.

Floor Surface Condition by Floor Materials by Heel Materials

The coefficient of friction values were highest for most of the hard floor surface materials with the standard polish and all heels.

The coefficient of friction values were lowest for most of the polished hard floor surface materials with the skid resistant polish and applied moisture for most heels. The exception was the leather heel for which the coefficient of friction values were always lowest on floor materials with the clear polish and applied moisture.

A discussion of the effects of polish and moisture upon the various floor surface materials by various heel materials will be discussed in the next chapter.

CHAPTER V

DISCUSSION OF RESULTS

This chapter will contain a section on floor materials, heel materials, and floor polishes with respect to the effects of polish and moisture upon the floor surface materials by heel materials. The graphs in the chapter will be used to compare the differences in the wet and dry and polished and unpolished conditions.

I. FLOOR MATERIALS

Terrazzo

Unpolished. There was little difference (less than .10) between the mean coefficients of friction of wet and dry unpolished terrazzo with all heels (Figure 1).

Polished. The mean coefficients of friction of polished terrazzo were always higher for the dry condition than with applied moisture for all heels with the exception of the standard polish on terrazzo with moisture applied and the nylon heel. With moisture applied to polished terrazzo and for all heels the coefficients of friction were higher with the standard polish than with the clear and skid resistant polishes.

Quarry tile

Unpolished. There was little difference (less than .10) between the mean coefficients of friction for dry and wet unpolished quarry tiles with nylon, rubber, and Neolite heels but there was a greater difference

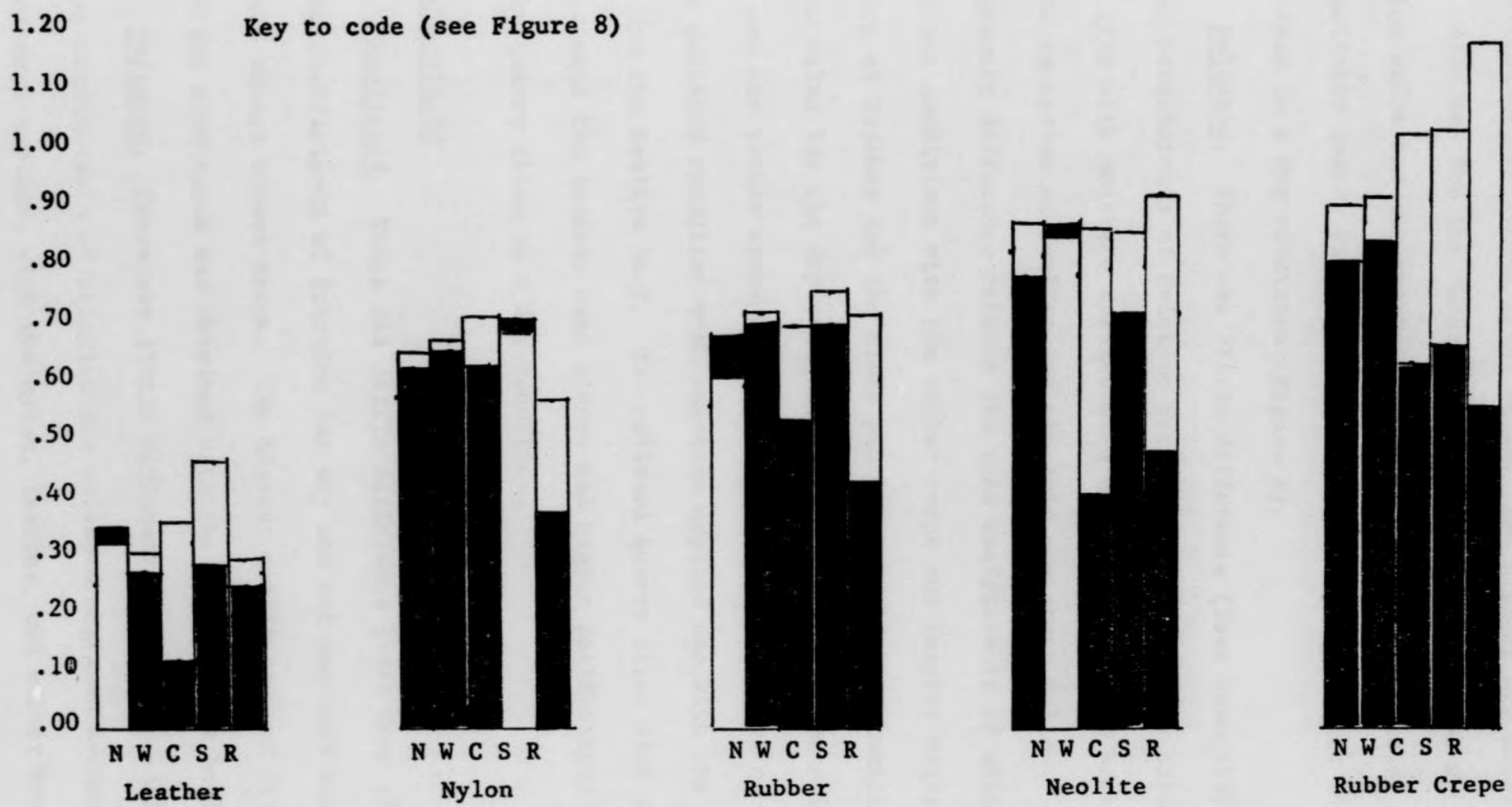

Figure 1. COEFFICIENTS OF FRICTION OF DRY AND WET UNPOLISHED AND POLISHED TERRAZZO AND VARIOUS HEEL MATERIALS

for the leather and rubber crepe heels. The highest dry unpolished condition value was for the rubber crepe heel and the highest wet unpolished condition value was for the Neolite heel. The coefficient of friction for the unpolished quarry tile with the leather heel was higher in a wet condition than in a dry condition (Figure 2).

Polished. There was little difference (less than .10) between the mean coefficients of friction for dry polished quarry tile and polished quarry tile with moisture applied with nylon, rubber, and Neolite heels with the exception of Neolite and the skid resistant polish. However, there was a greater difference between the mean coefficients of friction for the dry and wet conditions with the rubber crepe and leather heels with the exception of leather and the clear polish. The highest coefficient of friction value for the dry polished condition was with the skid resistant polish and the rubber crepe heel. The highest coefficient of friction value for the polished condition with moisture applied was with the standard polish and the Neolite heel. The polished quarry tiles with applied moisture and with the leather heel always had higher coefficients of friction than the quarry tiles in a dry condition.

Ceramic unglazed

Unpolished. There was little difference (less than .10) between the mean coefficients of friction for dry and wet unglazed ceramic with all heels except rubber crepe. The highest coefficient of friction value for the dry conditions was obtained with the rubber crepe heel (Figure 3).

Polished. There was little difference (less than .12) between the mean coefficients of friction for polished unglazed ceramic dry and with moisture applied, with the nylon, leather, and rubber heels.

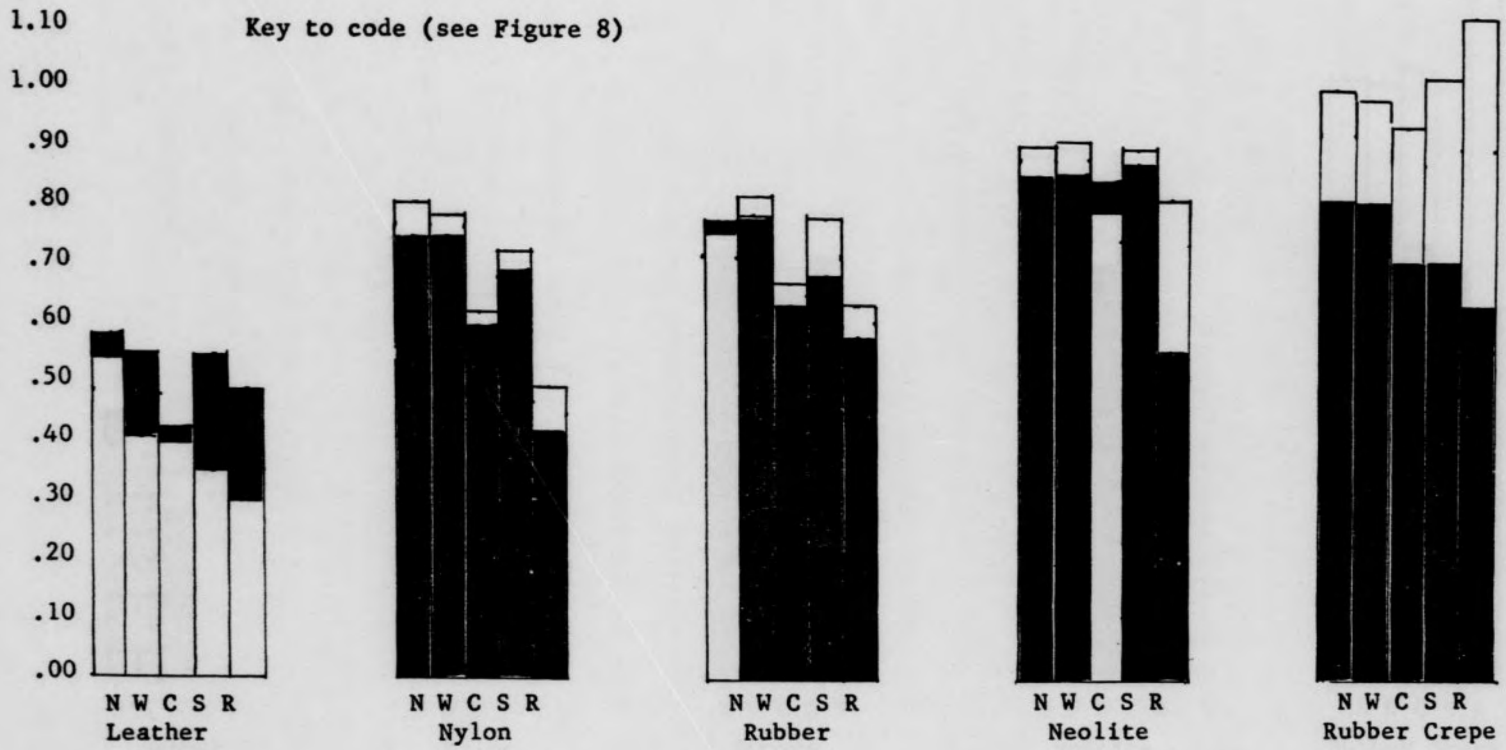

Figure 2. COEFFICIENTS OF FRICTION OF DRY AND WET UNPOLISHED AND POLISHED QUARRY TILE AND VARIOUS HEEL MATERIALS

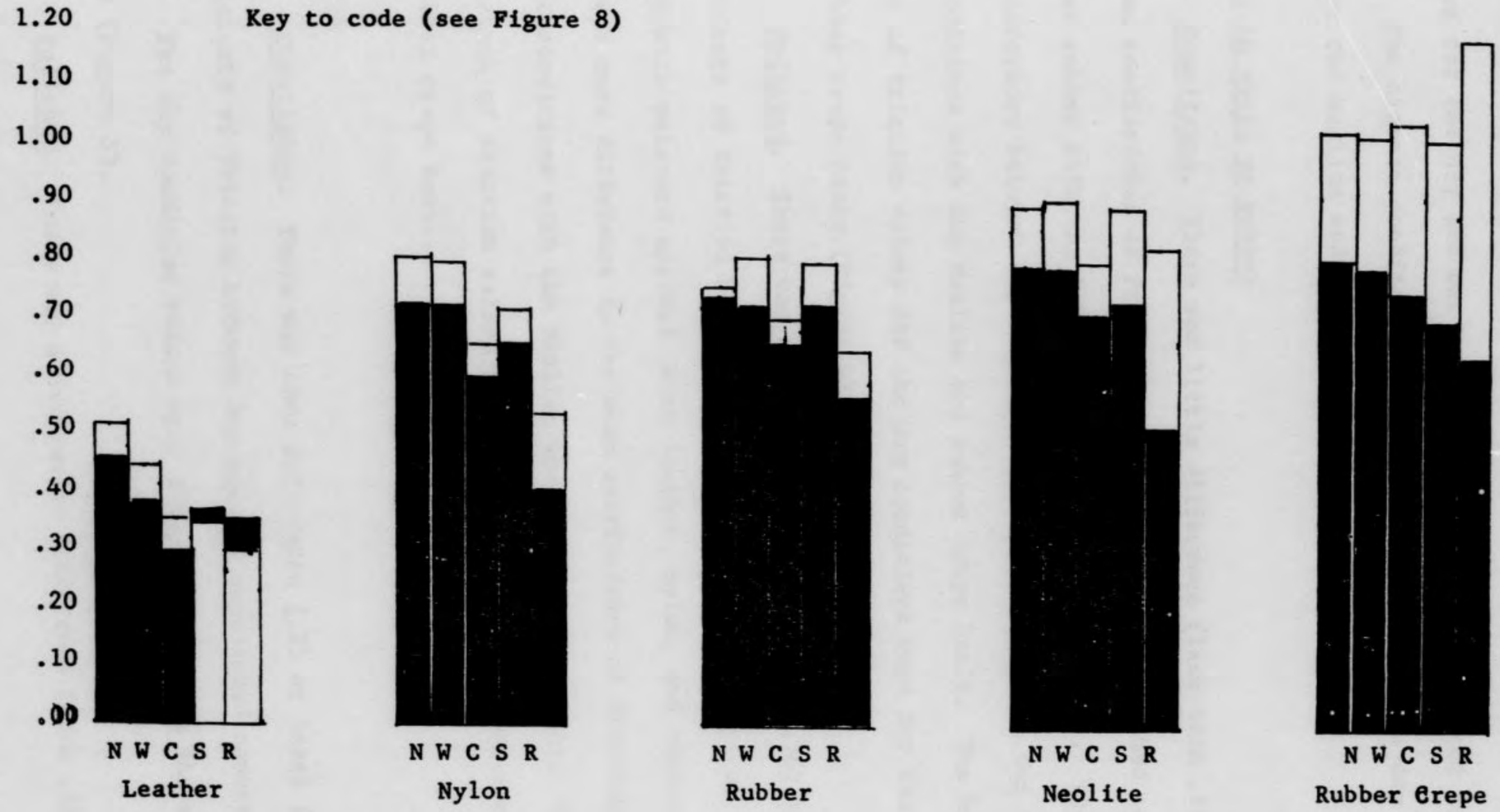

Figure 3. COEFFICIENTS OF FRICTION OF DRY AND WET UNPOLISHED AND POLISHED CERAMIC UNGLAZED AND VARIOUS HEEL MATERIALS

However, there was a greater difference between the mean coefficients of friction for the dry and wet conditions with the Neolite and rubber crepe heels. The highest coefficient of friction values for the dry conditions were for the Neolite and rubber crepe heels.

Ceramic in vinyl or rubber

Unpolished. There was little difference (less than .11) between the mean coefficients of friction for dry and wet unpolished ceramic in vinyl or rubber with the leather, nylon, and rubber heels. There was more difference between the mean coefficients of friction for the dry and wet conditions with the Neolite and rubber crepe heels. The highest coefficient of friction values for the dry conditions were for the Neolite and rubber crepe heels (Figure 4).

Polished. There was some difference (less than .16) in the mean coefficients of friction between polished ceramic in vinyl or rubber, dry and with moisture applied, with leather, nylon, and rubber heels. There was more difference in the mean coefficients of friction for the dry and wet conditions with the Neolite and rubber crepe heels. The highest coefficient of friction values for the dry conditions were for the Neolite and rubber crepe heels.

Concrete

Unpolished. There was some difference (.25 or less) in the mean coefficients of friction between dry and wet unpolished concrete with all heels. The dry condition values were always higher than the wet condition values (Figure 5).

Polished. There was a noticeable difference (from .12 to .62) in

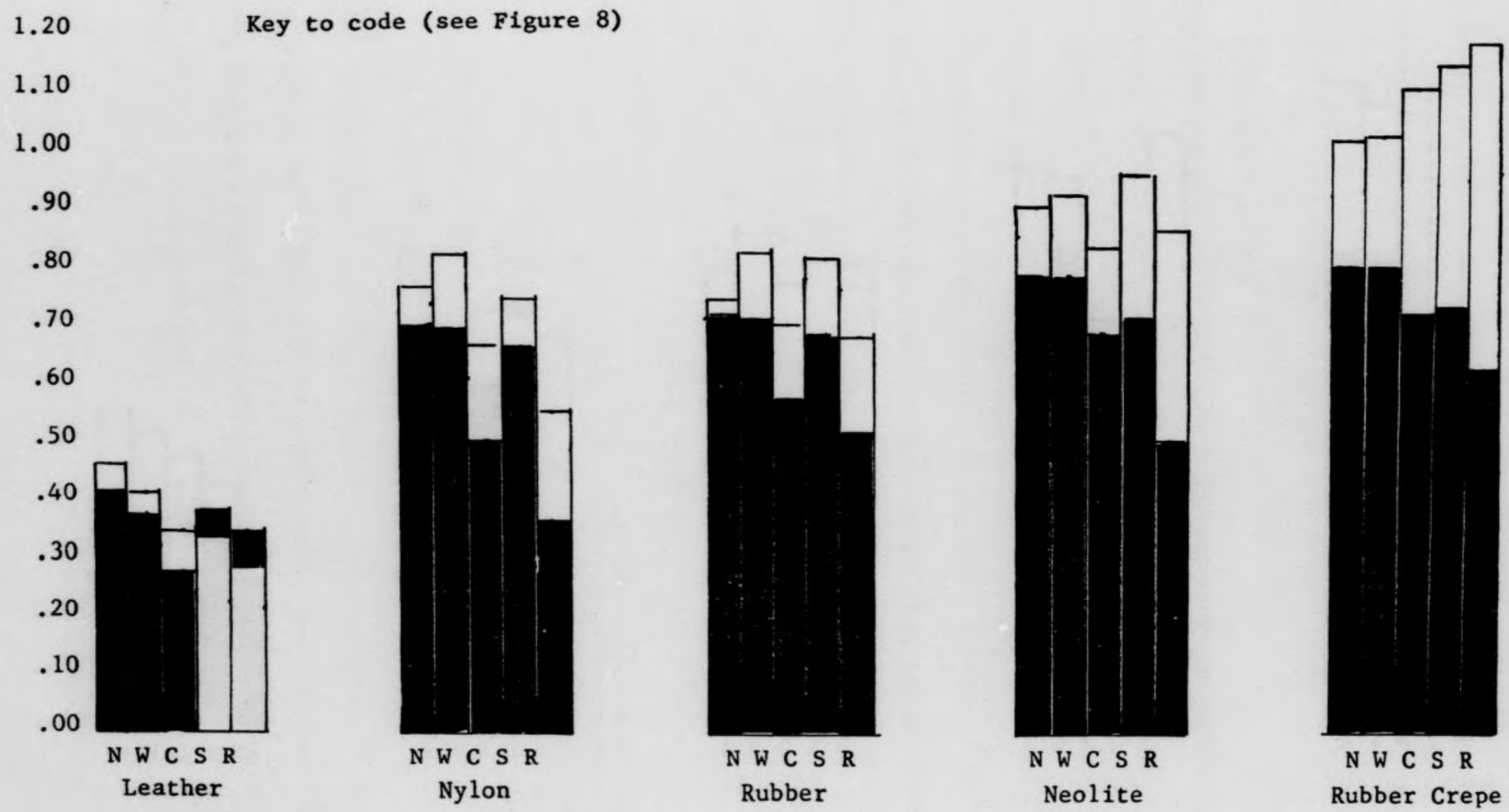

Figure 4. COEFFICIENTS OF FRICTION OF DRY AND WET UNPOLISHED AND POLISHED CERAMIC IN VINYL OR RUBBER AND VARIOUS HEEL MATERIALS

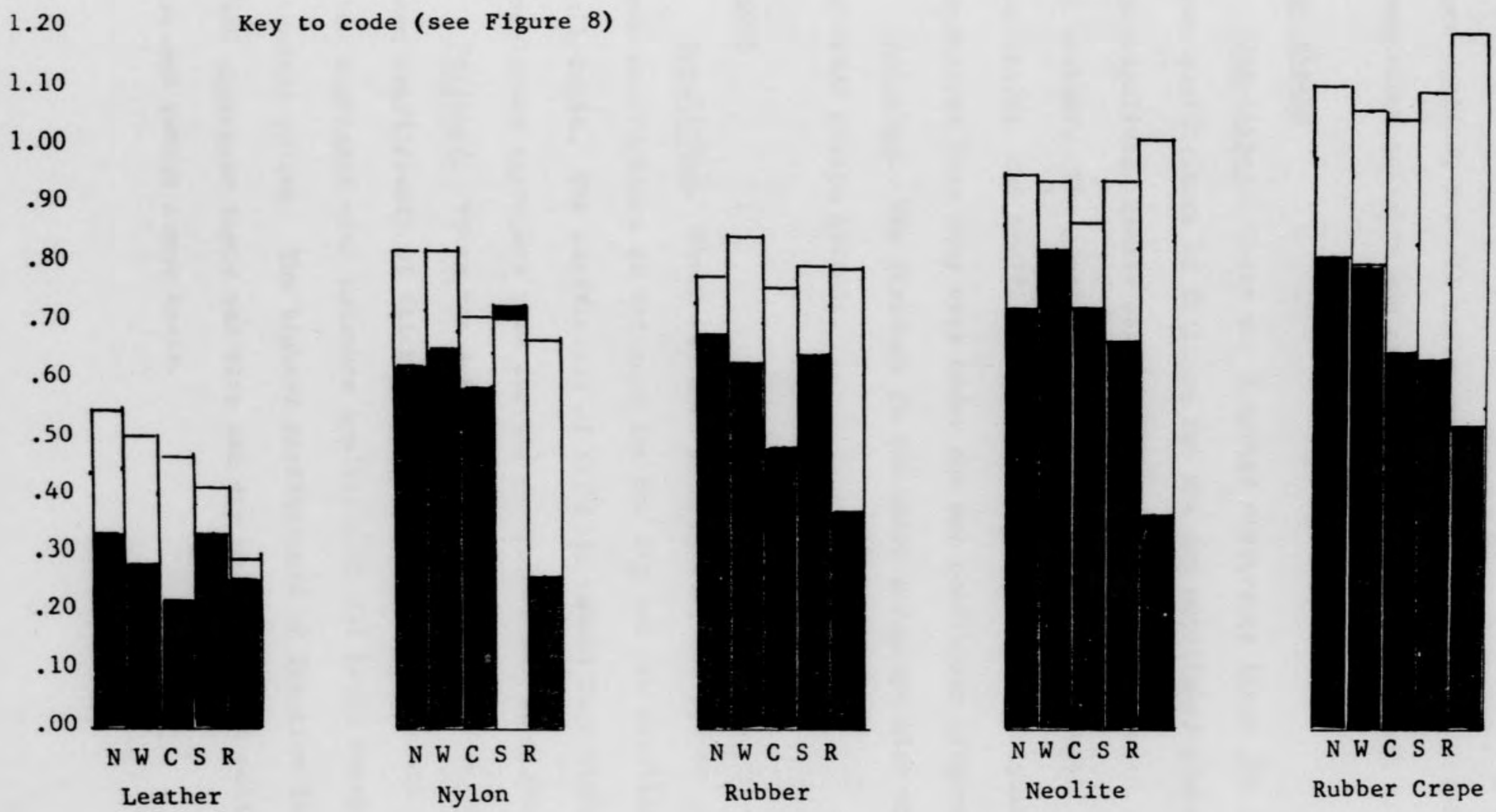

Figure 5. COEFFICIENTS OF FRICTION OF DRY AND WET UNPOLISHED AND POLISHED CONCRETE AND VARIOUS HEEL MATERIALS

the mean coefficients of friction between polished concrete, dry and with moisture applied, for all heels, except leather with the standard and skid resistant polishes and nylon with the standard polish.

Ceramic glazed

Unpolished. There was a marked difference (from .24 to .62) in the mean coefficients of friction for the dry unpolished glazed ceramic and the unpolished glazed ceramic with moisture applied with all heels except leather. The greatest differences were for the rubber crepe and Neolite heels. The coefficient of friction values were higher under the dry conditions than they were under the wet conditions (Figure 6).

Polished. The findings in the above paragraph also applied to the polished glazed ceramic.

Aggregate

Unpolished. There was some difference (from .08 to .27) between the mean coefficients of friction for the dry and wet unpolished aggregate with all heels. The coefficient of friction values were higher for the dry unpolished aggregate than for the wet unpolished aggregate (Figure 7).

Polished. There was a noticeable difference (from .10 to .66) in the mean coefficients of friction for the polished aggregate dry and the polished aggregate with moisture applied with all heels except nylon and the standard polish. The highest coefficients of friction for all polished aggregate tests was with the dry skid resistant polish and Neolite and rubber crepe heels.

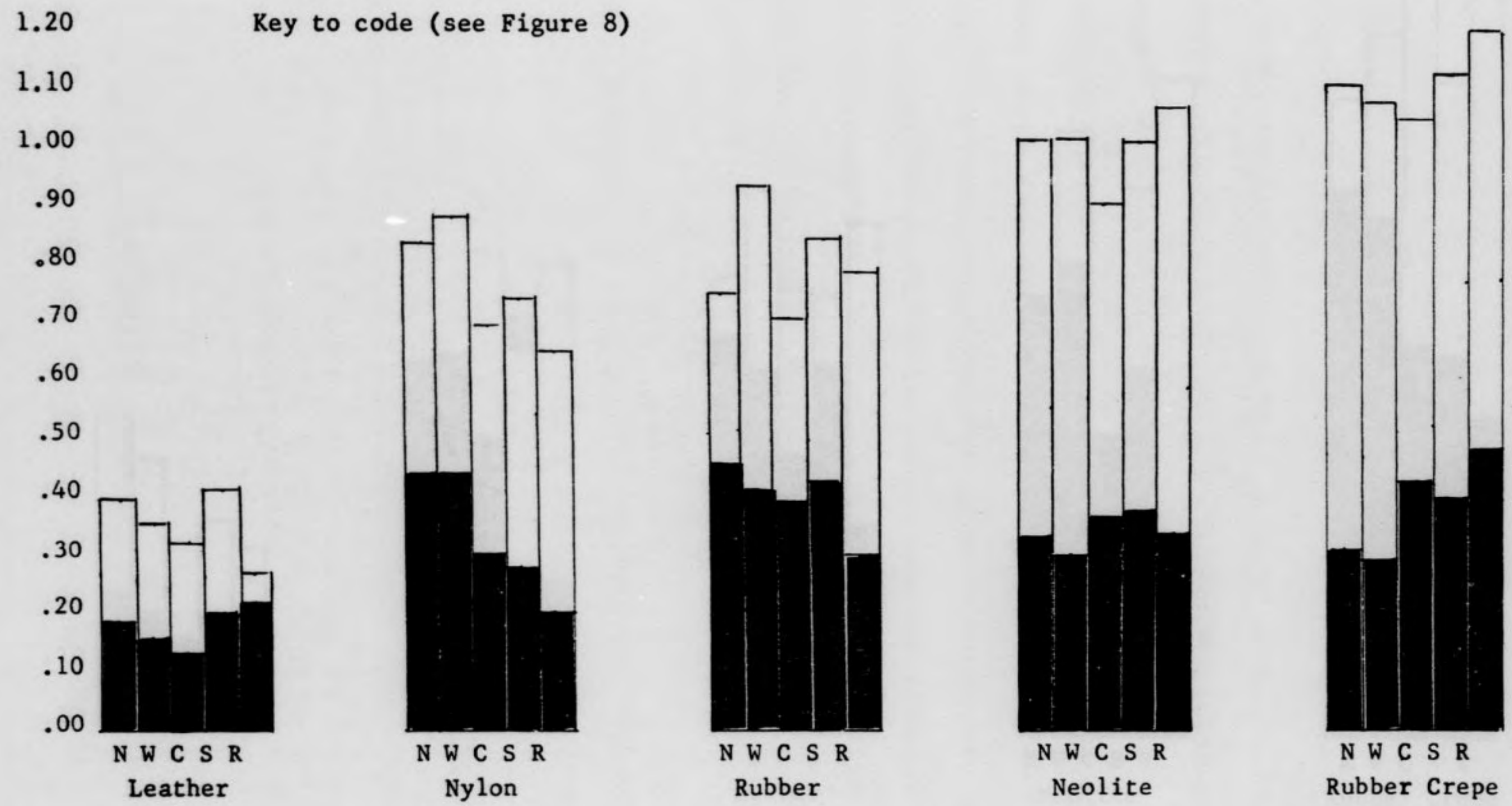

Figure 6. COEFFICIENTS OF FRICTION OF DRY AND WET UNPOLISHED AND POLISHED CERAMIC GLAZED AND VARIOUS HEEL MATERIALS

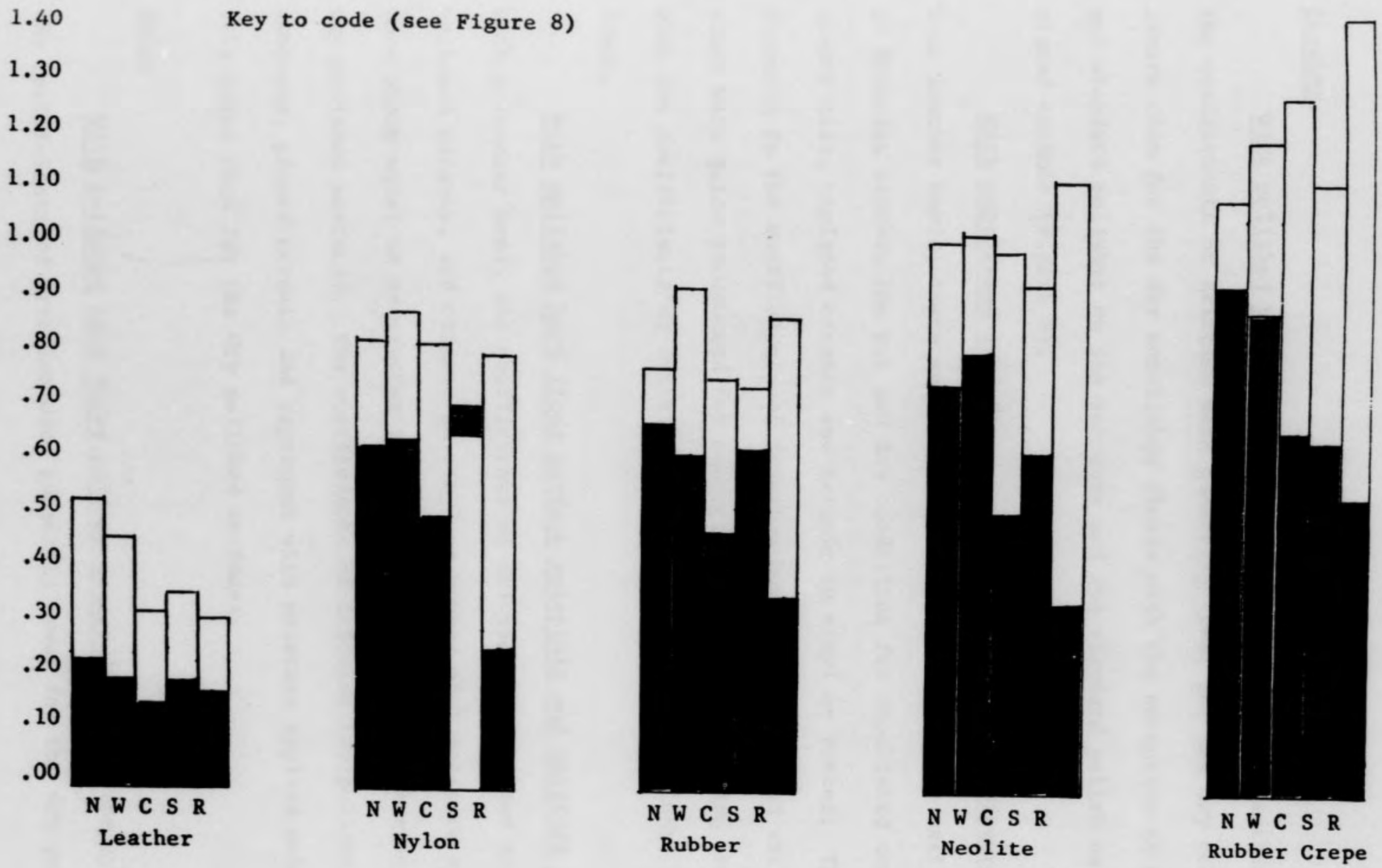

Figure 7. COEFFICIENTS OF FRICTION OF DRY AND WET UNPOLISHED AND POLISHED AGGREGATE AND VARIOUS HEEL MATERIALS

II. HEEL MATERIALS

Leather

With polished hard floor surface materials. With leather heels the coefficients of friction were generally lower for the dry polished floors than for the dry unpolished floors with the exception of the clear and standard polishes on the terrazzo and the standard polish on the glazed ceramic (Figure 8).

With unpolished hard floor surface materials and moisture applied. With leather heels, there was very little difference in the coefficients of friction between the wet and dry conditions for unpolished terrazzo, quarry tile, unglazed ceramic and ceramic in vinyl or rubber. The differences in the coefficients of friction between the dry and wet conditions were quite pronounced for concrete, glazed ceramic, and the aggregate with the coefficients of friction for the wet conditions always being lower.

With polished hard floor surface materials and moisture applied. With a leather heel, the coefficients of friction of polished quarry tile, unglazed ceramic, and ceramic in vinyl or rubber with moisture applied were about equal to or greater than the coefficients of friction for these dry polished surfaces. The coefficients of friction for polished terrazzo, concrete, glazed ceramic and aggregate with moisture applied were appreciably lower than for the dry polished surfaces.

Nylon

With polished hard floor surface materials. With the nylon heel, the coefficients of friction were generally lower for the dry polished

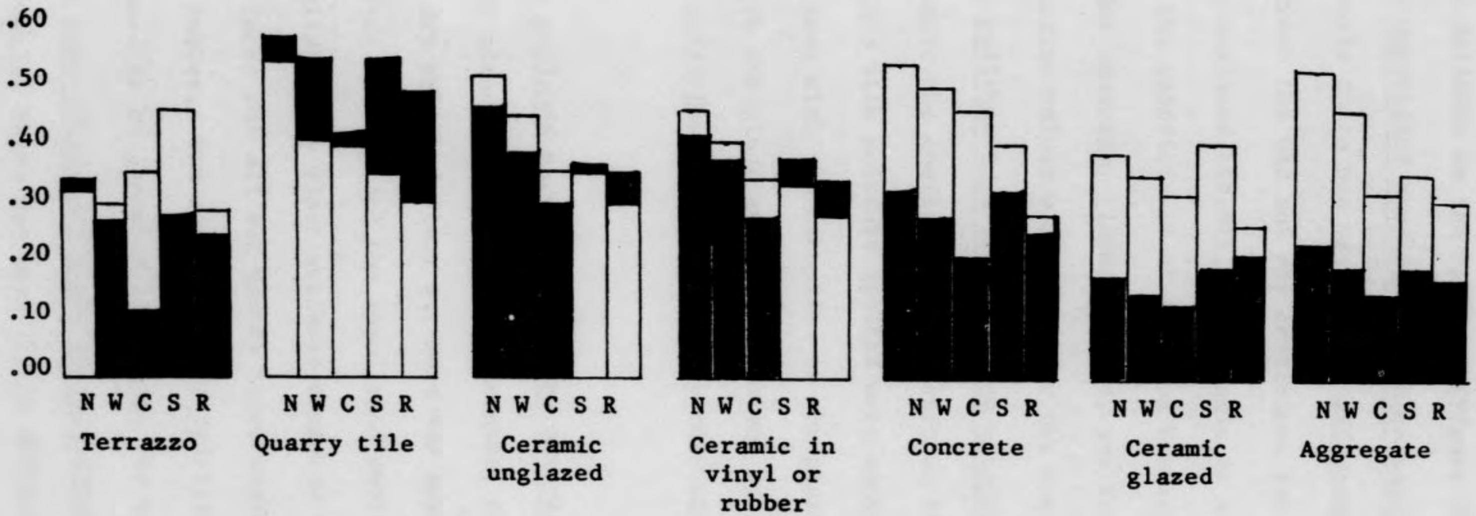

Figure 8

COEFFICIENTS OF FRICTION OF DRY AND WET UNPOLISHED AND POLISHED HARD FLOOR SURFACE MATERIALS AND LEATHER HEELS

= Dry

= With moisture applied

Unpolished
N = New
W = Worn

Polished
C = Clear polish
S = Standard
R = Skid resistant

floors than for the dry unpolished floors with the exception of the clear and standard polishes on the terrazzo (Figure 9).

With unpolished hard floor surface materials and moisture applied. With nylon heels there was very little difference in the coefficients of friction between the wet and dry conditions for unpolished terrazzo, quarry tile, unglazed ceramic, and ceramic in vinyl or rubber. The differences in the coefficients of friction between wet and dry were quite pronounced for concrete, glazed ceramic, and the aggregate. The coefficient of friction values were lower for the wet condition.

With polished hard floor surface materials and moisture applied. With nylon heels the coefficients of friction of the standard polished floor materials with moisture applied were approximately the same as for the dry surfaces with the exception of the glazed ceramic. The floor materials with the clear and skid resistant polishes and with nylon heels had higher coefficients of friction dry than with moisture applied.

Rubber

With polished hard floor surface materials. With rubber heels and all floor materials except the aggregate, the coefficient of friction of standard dry polished floor surfaces was approximately equal to the coefficients of friction of the unpolished surfaces (Figure 10). The skid resistant polished dry floor surfaces compared favorably with the unpolished surfaces for all but quarry tile, unglazed ceramic, and ceramic in vinyl or rubber. The coefficient of friction of the clear polished surfaces tended to be somewhat lower than the unpolished surfaces.

With unpolished hard floor surface materials and moisture applied. With rubber heels, there was very little difference in the coefficients

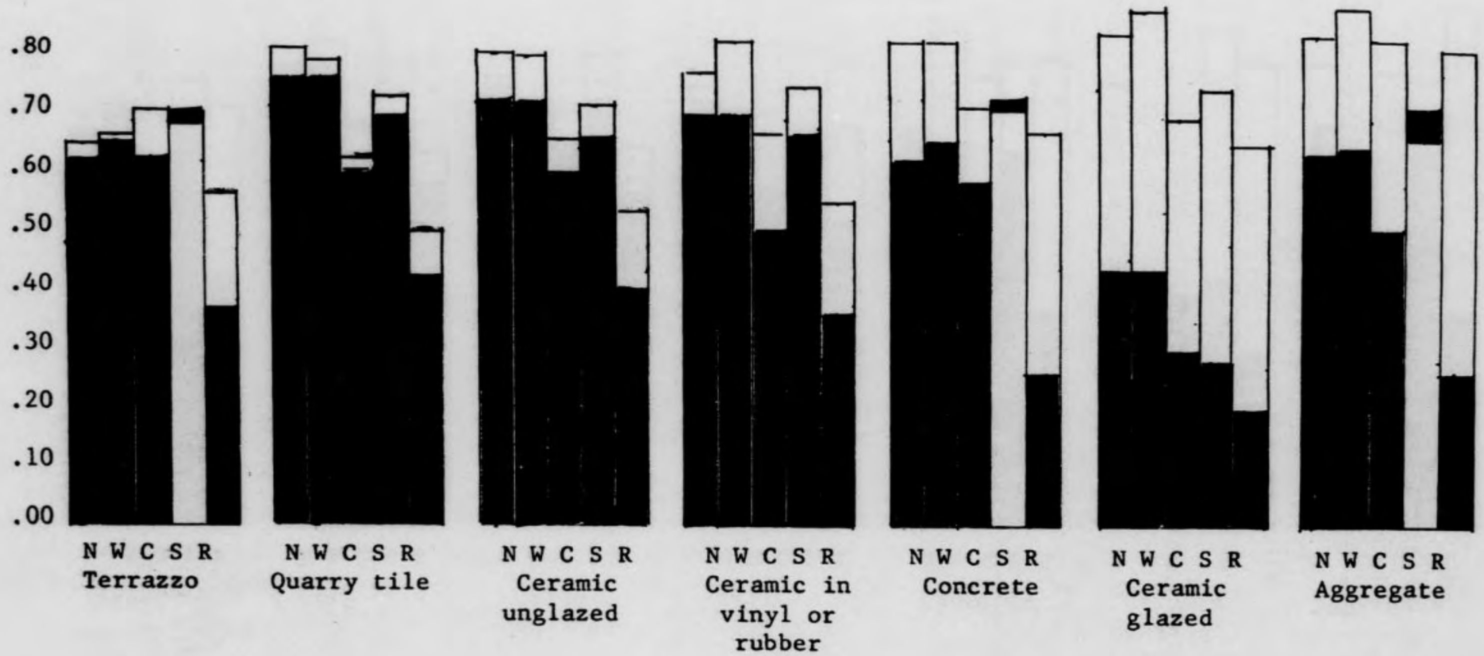

Figure 9

COEFFICIENTS OF FRICTION OF DRY AND WET UNPOLISHED AND POLISHED HARD FLOOR SURFACE MATERIALS AND NYLON HEELS

☐ = Dry

■ = With moisture applied

Unpolished
N = New
W = Worn

Polished
C = Clear polish
S = Standard
R = Skid resistant

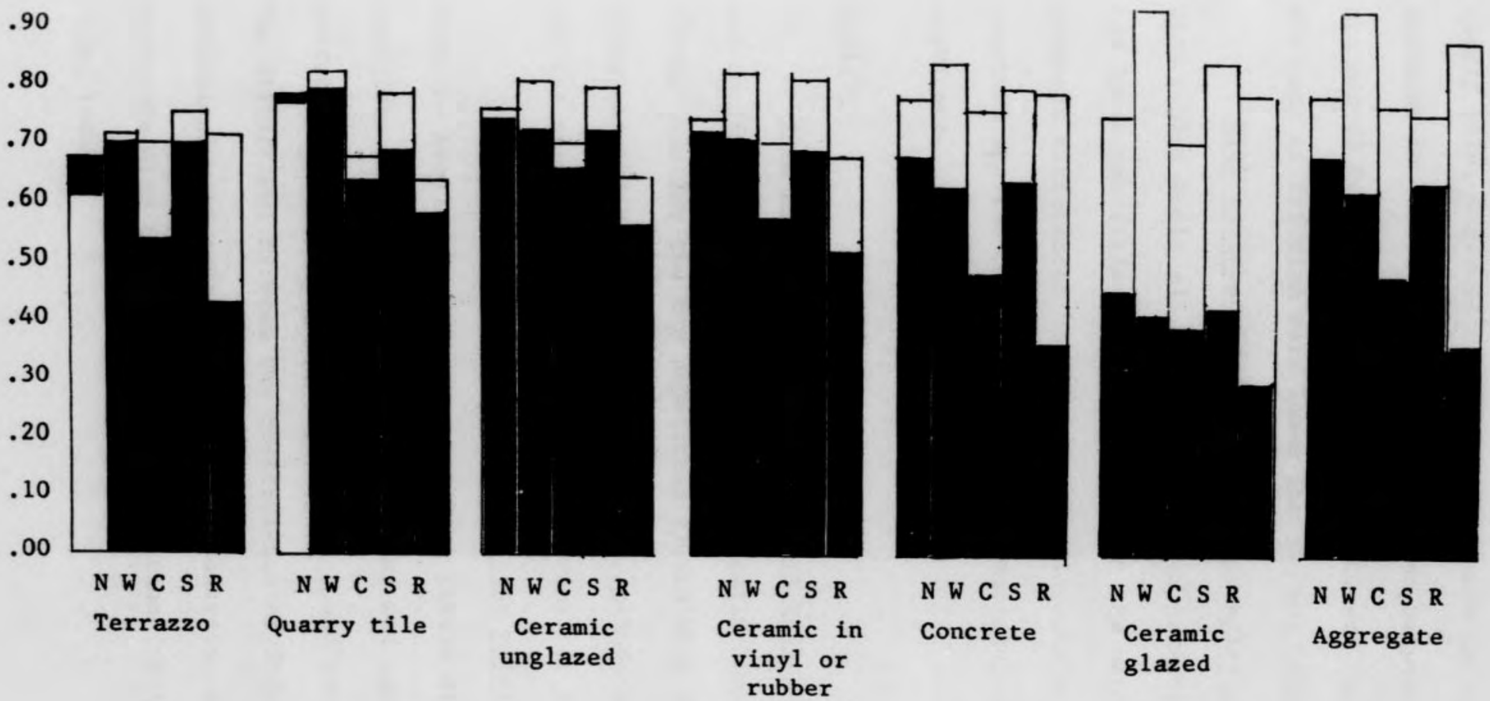

Figure 10

COEFFICIENTS OF FRICTION OF DRY AND WET UNPOLISHED AND POLISHED HARD FLOOR SURFACE MATERIALS AND RUBBER HEELS

= Dry

= With moisture applied

Unpolished
N = New
W = Worn

Polished
C = Clear polish
S = Standard
R = Skid resistant

of friction between the wet and dry conditions for unpolished terrazzo, quarry tile, unglazed ceramic, and ceramic in vinyl or rubber. The differences in the coefficients of friction between wet and dry were quite pronounced for concrete, glazed ceramic, and the aggregate. The coefficients of friction were lower for the wet condition.

With polished hard floor surface materials and moisture applied. With rubber heels all the polished floor surfaces with moisture applied had lower coefficients of friction than the unpolished surfaces. The greatest differences between the coefficients of friction for the dry and moisture applied conditions were for concrete, glazed ceramic, and the aggregate.

Neolite

With polished hard floor surface materials. With the Neolite heels the coefficients of friction were generally lower for the dry polished floors than for the dry unpolished floors with the exception of the skid resistant polish on terrazzo, concrete, glazed ceramic, and the aggregate and the standard polish on ceramic in vinyl or rubber (Figure 11).

With unpolished hard floor surface materials and moisture applied. With the Neolite heels, there was very little difference between the coefficients of friction for the dry and wet conditions for unpolished terrazzo, quarry tile, unglazed ceramic, and ceramic in vinyl or rubber. The differences between the coefficients of friction for the dry and wet conditions were quite pronounced for concrete, glazed ceramic, and the aggregate with the coefficient of friction for the wet condition always being lower.

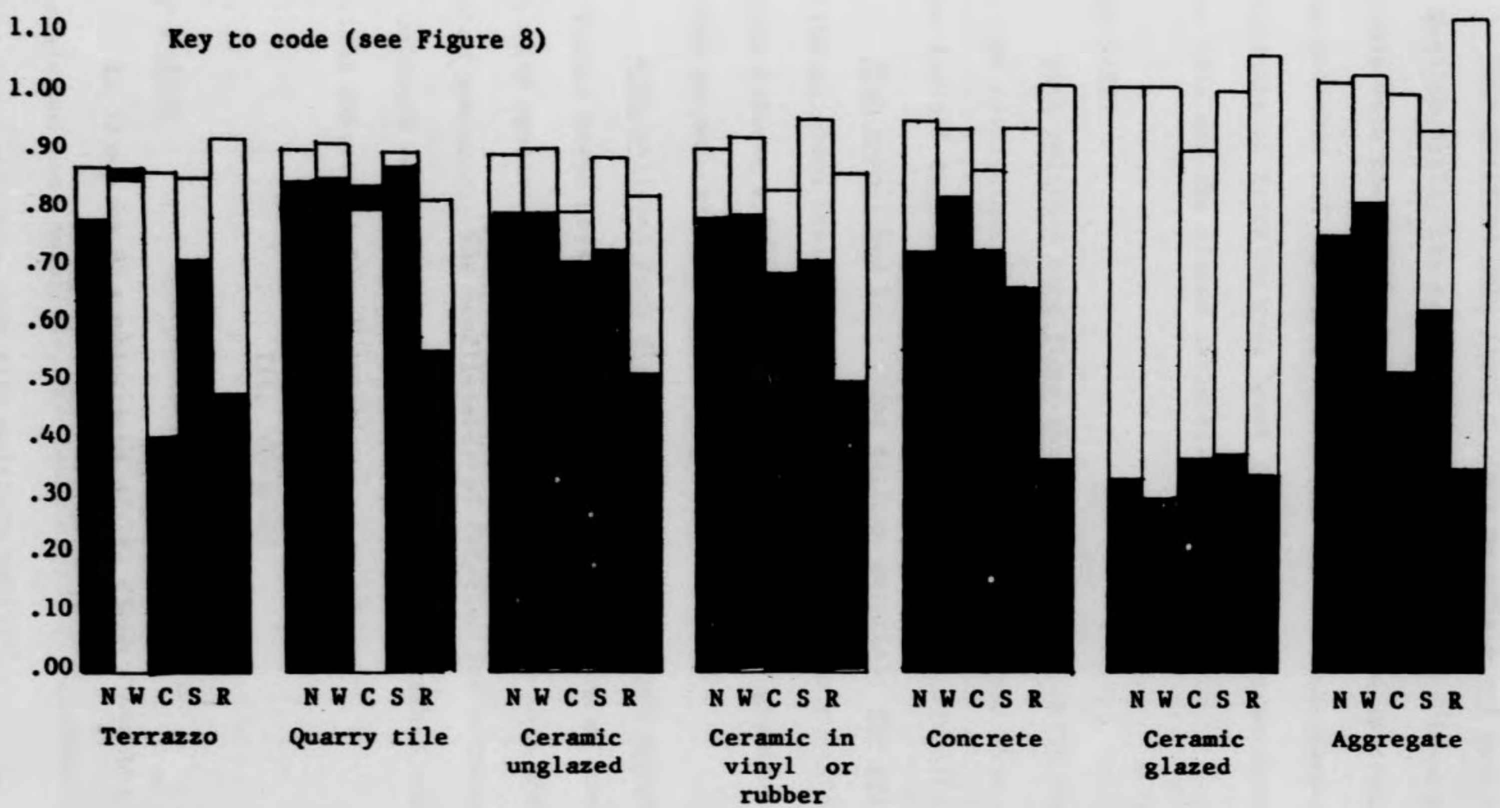

Figure 11. COEFFICIENTS OF FRICTION OF DRY AND WET UNPOLISHED AND POLISHED HARD FLOOR SURFACE MATERIALS AND NEOLITE HEELS

With polished hard floor surface materials and moisture applied. With Neolite heels, the coefficients of friction were lowest for all materials with the skid resistant polish and applied moisture. In comparing polished and unpolished floor surfaces with moisture applied, the coefficients of friction were lower for the polished surfaces except for quarry tile and the glazed ceramic.

Rubber crepe

With polished hard floor surface materials. With the rubber crepe heels the coefficients of friction was highest for the skid resistant polish for all dry hard floor surface materials (Figure 12).

With unpolished hard floor surface materials and moisture applied. With rubber crepe heels, the least difference in the coefficients of friction between wet and dry was with terrazzo; the greatest difference was with ceramic glazed.

With polished hard floor surface materials and moisture applied. With rubber crepe heels, the coefficients of friction of the polished surfaces with applied moisture were considerably lower than for the dry polished surfaces. The coefficients of friction for polished materials with moisture applied were lower than the wet unpolished for all floor materials except the glazed ceramic.

III. POLISHES

Clear polish

In 33 of the 35 combinations of the clear floor polish, floor materials and heel materials, the coefficients of friction were higher for the dry conditions than with moisture applied.

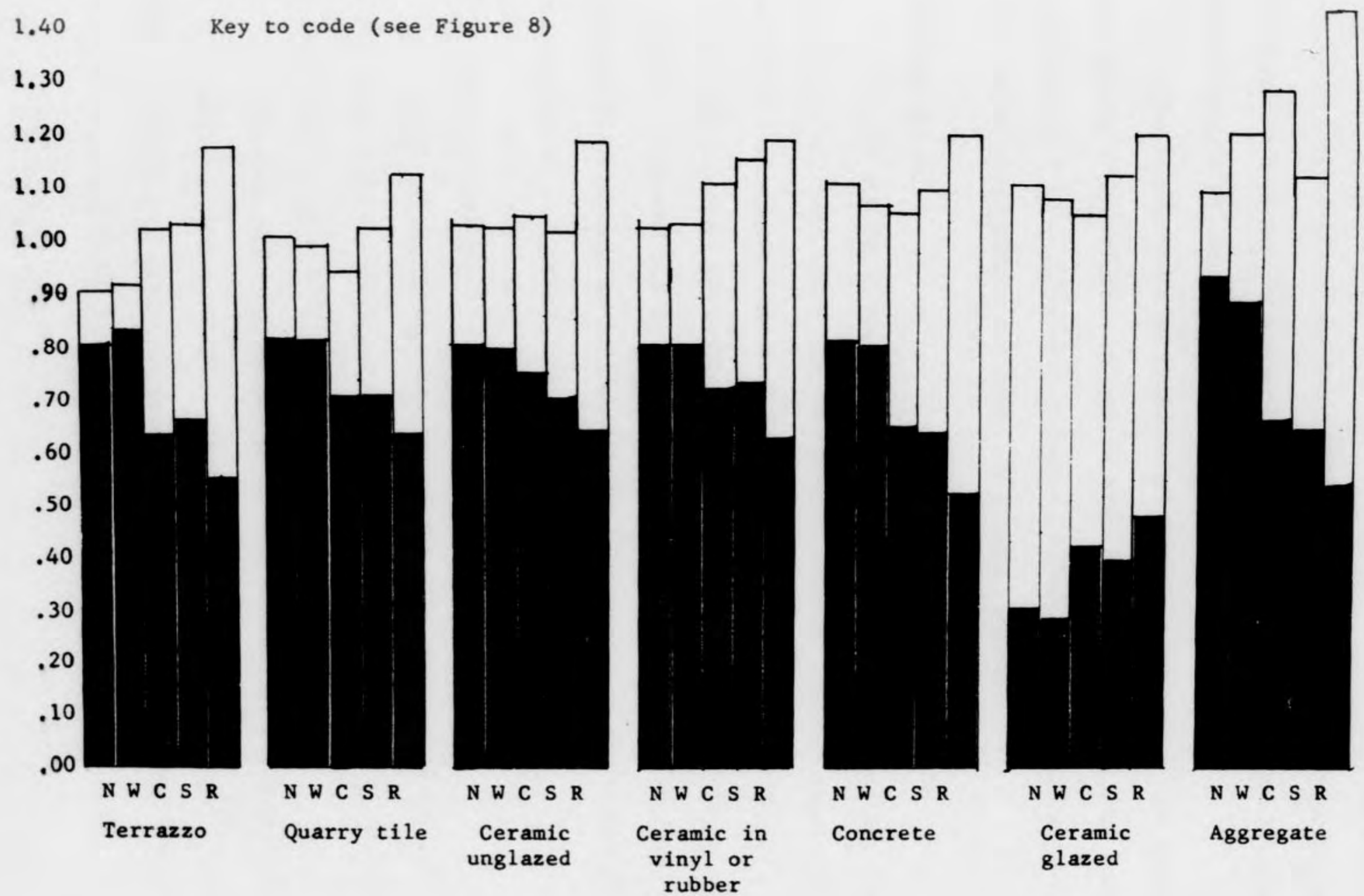

Figure 12. COEFFICIENTS OF FRICTION OF DRY AND WET UNPOLISHED AND POLISHED HARD FLOOR SURFACE MATERIALS AND RUBBER CREPE HEELS

The clear polish in 35 combinations of the materials in a dry condition increased the coefficient of friction in five combinations made no appreciable change in six combinations and decreased the coefficient of friction in 24 combinations.

The coefficients of friction of the clear polished floor materials with moisture applied were higher in three combinations than when these same materials were unpolished and moisture was applied, approximately the same in one combination, and lower in 31 combinations.

Standard polish

In 29 out of 35 combinations of the standard floor polish, floor materials, and heel materials, the coefficients of friction were higher for the dry condition than with applied moisture.

The standard polish in 35 combinations of the materials in a dry condition increased the coefficient of friction in six combinations, made no appreciable change in 15 combinations, and decreased the coefficient of friction in 14 combinations.

Skid resistant polish

In 32 of the 35 combinations of the skid resistant floor polish, floor materials, and heel materials, the coefficients of friction were higher for the dry condition than with applied moisture.

The skid resistant polish in 35 combinations of the materials in a dry condition increased the coefficient of friction in 11 combinations, made no appreciable change in four combinations, and decreased the coefficient of friction in 20 combinations.

The coefficients of friction of the skid resistant polished floor materials with moisture applied were higher in two combinations than when these same materials were unpolished and moisture was applied, approximately the same in one combination, and lower in 32 combinations.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

I. SUMMARY

The purposes of this study were as follows:

1. To determine the coefficients of friction between hard floor surfaces (ceramic tile, terrazzo, concrete, and aggregate) and various heel materials (leather, rubber, rubber crepe, Neolite, and nylon).

2. To determine the effect of three different floor polishes on the coefficients of friction of hard floor surfaces.

3. To determine the effect of applied moisture on the coefficients of friction of unpolished and polished hard floor surfaces.

A testing apparatus was used to measure the force of kinetic friction of unpolished and polished hard floor surface materials with various heel materials.

The seven floor materials included aggregate, ceramic glazed, ceramic unglazed, ceramic in vinyl or rubber, concrete, quarry tile, and terrazzo. Two test panels from each of two manufacturers were secured for a total of four test panels for each type of floor material. The 28 test panels were arranged in two randomized block designs on the surface of the testing machine.

Two samples representing two manufacturers of each of five heel types were secured. The samples included leather, Neolite, nylon, rubber and rubber crepe. The face finish was worn off each heel so that complete contact could be made between the heel and floor materials. The order of testing the heels was randomized. A weight load of 25 pounds was used on each heel.

One sample from each of three kinds of water emulsion polish was secured. The three kinds of polishes were standard, clear, and skid resistant.

The floor materials were tested dry and with moisture applied in new, worn, and polished conditions. A total of 85 tests were run for a total of 3,920 force of friction measurements.

Analysis of variance was the method employed in analyzing the data. The three analysis of variance models used were:

1. An analysis of the dry unpolished and polished hard floor surface materials.
2. An analysis of the new and worn (unpolished) hard floor surface materials with moisture applied.
3. An analysis of the polished hard floor surface materials with moisture applied.

Highly significant differences ($P \leq .001$) were found in the mean force of friction measurements among the dry unpolished and polished floor materials and among the polished floor materials with moisture applied. The aggregate floor material had the highest coefficient of friction and terrazzo the lowest for the dry unpolished and polished hard floor surface materials. The quarry tile had the highest coefficient of friction and the glazed ceramic had the lowest for the polished hard floor surface materials with applied moisture.

Significant differences ($P \leq .01$) were found in the mean force of friction measurements among the hard floor surface materials for the wet unpolished (new and worn) materials. The quarry tile had the highest coefficient of friction and the glazed ceramic the lowest for the wet unpolished hard floor surface materials.

Significant differences ($P \leq .01$) were found in the mean force of friction measurements among the various heel materials on the dry unpolished and polished hard floor surface materials. The leather heel material had the lowest coefficient of friction and rubber crepe the highest for the dry unpolished and polished hard floor surface materials.

Highly significant differences ($P \leq .001$) were found in the mean force of friction measurements among the various heel materials on the unpolished (new and worn) and polished hard floor surface materials with moisture applied. The leather heel material had the lowest coefficient of friction and rubber crepe the highest for the unpolished and polished hard floor surface materials with moisture applied. The rubber crepe heel had a higher coefficient of friction under all conditions than the other heels.

The differences in the mean forces of friction for the polishes were not significant until individual degrees of freedom were calculated. The coefficients of friction of the floor materials with the skid resistant polish were found to be significantly different from the clear and standard polished floor materials. Of the three polishes, the skid resistant polished floor materials had the highest coefficient of friction dry and the standard polished floor materials the highest coefficient of friction with moisture applied. The clear polished floor materials had the lowest coefficient of friction dry and the skid resistant polished floor materials had the lowest coefficient of friction with moisture applied.

The differences in the coefficient of friction values between the floor materials under dry and wet conditions for all heel materials were generally greater for concrete, glazed ceramic, and the aggregate than were the differences between the floor materials under dry and wet conditions for terrazzo, quarry tile, unglazed ceramic, and ceramic in vinyl or rubber. The hard floor surface materials generally had higher coefficients of friction in a dry condition than in a wet condition except when tested with the leather heel.

The dry polished hard floor surface materials, with the exception of terrazzo, generally had a lower coefficient of friction than the dry unpolished materials when tested with the leather, nylon, and rubber heel materials. However, the dry polished floor materials generally had a higher coefficient of friction than the dry unpolished materials with Neolite and rubber crepe heels. The polished hard floor surface materials with moisture applied generally had a lower coefficient of friction than the unpolished floor materials with moisture applied.

II. CONCLUSIONS

From the results of this study in which seven hard floor surface materials (aggregate, glazed ceramic, unglazed ceramic, ceramic in vinyl or rubber, concrete, quarry tile, and terrazzo) were tested with five heel materials (leather, Neolite, nylon, rubber, rubber crepe) in dry unpolished and polished conditions and in unpolished and polished conditions with moisture applied, the following conclusions are drawn:

1. There are some differences in the skid resistances of the seven hard floor surface materials which were tested. Terrazzo is the least skid resistant and

aggregate the most skid resistant when dry unpolished or polished as compared to the other materials. Glazed ceramic is generally the least skid resistant and quarry tile is generally the most skid resistant when unpolished or polished with moisture applied.

2. There are marked differences in skid resistance among the five heel materials tested. Under all conditions leather is generally less skid resistant and rubber crepe more skid resistant than the other heel materials.

3. Hard floor surface materials and heel materials do not have a single force of friction measurement but rather the force of friction measurement depends upon the hard floor surface materials to which the various heels are applied.

4. Polishes generally lower the skid resistance of hard floor surface materials, especially the clear and skid resistant polishes with moisture applied.

5. The skid resistant polish does not generally show more skid resistant properties either dry or with moisture applied than the standard and clear polishes with leather, nylon, and rubber heels. The skid resistant polish does show skid resistant properties for the Neolite and rubber crepe heels when tested under dry conditions.

6. Moisture generally lowers the skid resistance of unpolished and polished hard floor surface materials.

III. RECOMMENDATIONS

Two recommendations for further study are as follows:

1. That a more extensive study of skid resistance be conducted on hard floor surface materials with several brands of both water emulsion and solvent base polishes.

2. That the skid resistance of hard wood floor surfaces and their finishes be studied in order to have skid resistance data for comparing the three major types of flooring: resilient, hard, and wood floor surfaces.

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APPENDIX

APPENDIX A

GLOSSARY

Aggregate: a mixture of stone, rocks, shells, or pebbles embedded in a transparent or opaque plastic resin base

Ceramic tile (unglazed): tile made wholly or partly of clay and baked

Ceramic tile (glazed): tile having an "overlay ... with a substance which gives a glassy finish when fused"[1]

Ceramic tile (in vinyl or rubber): ceramic tile which has been embedded in a vinyl or rubber base

Coefficient of friction: the ratio between the force of friction and the normal force which holds two surfaces together

Concrete: "a mixture of water, Portland cement, and aggregate which may be sand or gravel or a mixture of these"[2] and which dries to a stone-like product

Leather: "a material consisting of animal skin prepared for use by removing the hair and tanning."[3]

Neolite: "is the trade name for a rubber resin composition material manufactured and sold by the Goodyear tire and Rubber Company ... Neolite and comparable products are composed of various blends of natural and synthetic rubber, the most important synthetic being styrene butadiene (SBR), Hycar and Neoprene."[4]

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[1] Webster's New Twentieth Century Dictionary (Cleveland and New York: The World Publishing Company, 1957), p. 775.

[2] Bernard Berkeley, Cyril S. Kimball, "The Care, Cleaning and Selection of Floor and Resilient Floor Coverings," (New York: Ahrens Book Company, Inc., 1961), p. 15.

[3] Webster's New ..., op. cit., p. 1032.

[4] Letter from J. S. Roney, Sales Engineer, The B. F. Goodrich Company, dated April 11, 1962.

Nylon: "generic title for a group of compounds called polyamides, substances which contain in their chains, besides carbon and hydrogen clusters, the amide group occurring at regular intervals."[5]

Quarry tile: a highly fired burned clay tile..."[6]

Rubber (and Rubber crepe): "A substance that is obtained from the latex of many tropical plants, characterized by its elasticity;..prepared by coagulating the latex, collecting the sticky coagulum, and either milling into rough sheets of rubber crepe or rolling into smooth or rubber sheets and drying."[7]

Terrazzo: "a flooring of small chips of marble set in cement and polished."[8]

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[5]B. H. Weil, Victor J. Anhorn, Plastic Horizons (Lancaster: Jaques-Cattell Press, 1944), p. 113.

[6]Quarry tile sample from Hood Ceramic Corporation

[7]Webster's Third New International Dictionary (Springfield: G. & C. Merriam Co., 1961), p. 1287.

[8]Webster's New ..., op. cit., p. 291.

Table I (Continued)

Source of variation	Degrees of freedom	Mean square	Error mean square	"F" ratio
Condition x floor materials x duplicates/heel materials	102	1.41	.82	1.72*
Conditions x heel materials x manufacturers/floor materials	112	2.96	1.57	1.89*
Conditions x heel materials x duplicates/manufacturers/floor materials	224	2.01	1.26	1.60**
Conditions x duplicates/heel materials x manufacturers/floor materials	119	.82	1.26	.70
Conditions x duplicates/heel materials x duplicates/manufacturers/floor materials	238	1.26		
	1316			

*P $\leq$ .01
**P $\leq$ .001

APPENDIX B

TABLE II

ANALYSIS OF VARIANCE OF THE FORCE OF FRICTION

OF NEW AND WORN (UNPOLISHED) HARD FLOOR SURFACE MATERIALS

WITH MOISTURE APPLIED

Source of variation	Degrees of freedom	Mean square	Error mean square	"F" ratio
Floor materials	6	668.38	60.94	10.97**
Manufacturers/floor materials	7	53.84	14.56	3.70
Duplicates/manufacturers/ floor materials	14	14.24	.49	29.06**
Heel materials	4	1365.28	61.38	22.24**
Duplicates/heel materials	5	54.40	.81	67.16**
Floor materials x heel materials	24	42.19	14.89	2.83**
Floor materials x duplicates/heel materials	30	7.91	.81	9.77**
Heel materials x manufacturers/floor materials	28	7.79	2.09	3.73**
Heel materials x duplicates/manufacturers/ floor materials	56	1.77	.49	3.61**
Duplicates/heel materials x manufacturers/floor materials	35	.81	.49	1.65
Duplicates/heel materials x duplicates/manufacturers/ floor materials	70	.49		
Conditions	1	1.80	5.60	.32
Conditions x floor materials	6	2.81	1.96	1.43
Conditions x heel materials	4	10.68	5.51	1.94
Conditions x floor material x heel materials	24	1.20	1.87	.64
Conditions x manufacturers/ floor materials	7	.66	1.40	.47
Conditions x duplicates/ manufacturers/floor materials	14	.79	.36	2.19
Conditions x duplicates/ heel materials	5	5.91	.97	6.09**

Table II (Continued)

Source of variation	Degrees of freedom	Mean square	Error mean square	"F" ratio
Conditions x floor materials x duplicates/heel materials	30	2.27	.97	2.34*
Conditions x heel materials x manufacturers/floor materials	28	.57	1.20	.48
Conditions x heel materials x duplicates/manufacturers/floor materials	56	.59	.36	1.64
Conditions x duplicates/heel materials x manufacturers/floor materials	35	.97	.36	2.69**
Conditions x duplicates/heel materials x duplicates/manufacturers/floor materials	70	.36		
	559			

*$p \leq .01$
**$p \leq .001$

APPENDIX B

TABLE III

ANALYSIS OF VARIANCE OF THE FORCE OF FRICTION OF POLISHED HARD FLOOR SURFACE MATERIALS WITH MOISTURE APPLIED

Source of variation	Degrees of freedom	Mean square	Error mean square	"F" ratio
Floor materials	6	262.24	31.79	8.25**
Manufacturers/floor materials	7	22.63	2.14	10.57**
Duplicates/manufacturers/ floor materials	14	2.14		
Heel materials	4	657.74	2.39	275.21**
Floor materials x heel materials	24	11.55	2.39	4.83**
Heel materials x manu- facturers/floor materials	28	2.39	1.21	1.98
Heel materials x duplicates/ manufacturers/floor materials	56	1.21		
Condition	2	449.33	61.95	7.25
Clear + standard vs skid resistant	1	779.80	61.95	12.59*
Clear vs standard	1	119.21	61.95	1.92
Condition x floor materials	12	13.10	2.96	4.43**
Condition x manufacturers/ floor materials	14	1.54		
Condition x duplicates/ manufacturers/floor materials	28	1.37		
Condition x heel materials	8	61.44	1.03	59.65**
Condition x floor materials x heel materials	48	2.45		
Condition x heel materials x manufacturers/floor materials	56	1.03		
Condition x heel material x duplicates/manufacturers/ floor materials	112	.52		
	419			

*P $\leq$ .01
**P $\leq$ .001

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