

EXPERIMENTAL STUDY OF HOW SLIP RESISTANCE IN EXISTING CERAMIC FLOORS DEVELOPS OVER TIME

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ABSTRACT

The main objective of this paper is to study how slip resistance (R_d) in ceramic flooring evolves over time under the current conditions in which it is used in different areas in several buildings at the Jaume I University in Castellon, Spain. To do so, the R_d reading for various types of ceramic tiles taken at zero time or in the absence of pedestrian traffic is compared with the R_d value obtained when the floor has been in normal service for a specific period of time.

In Spain, regulatory specifications as far as floor slipperiness is concerned are defined in Section SUA 1 "Safety against the risk of falling" in the Basic Document DB-SUA User Safety and Accessibility in the Technical Building Code.

The afore-mentioned regulation lays down a requirement for floors to meet the standards of specific floor classes depending on where they are used. Thus, floors are classified according to their slip resistance value (R_d), which is measured by means of a pendulum friction tester as described in Annex A of UNE-ENV standard 12633:2003, in the most unfavourable conditions of slipperiness. It also states that the floor must maintain its classification throughout its service life.

Knowledge about how the R_d property develops in specific floors will enable designers to select tiles that do not come near the lower class limit value as required by the current regulations mentioned above, especially when the requirement has to be met throughout the floor's entire working life.

At the same time, the influence of the floor's state of cleanness is assessed, i.e. an attempt is made to determine to what extent the actual dirtiness of the floor in service conditions influences its slip resistance rating.

1. INTRODUCTION

Slip resistance is the ability of a surface to maintain adherence with a pedestrian's footstep. It is complex to assess because it involves a multitude of factors relating to the actual person (weight, size, manner of walking, adaptability, perception and reaction, individual musculo-skeletal system,...) as well as the characteristics of his/her footwear (type of sole, material), of the surface being walked on (slope, flatness, lack or absence of protrusions, reliefs or texture,...), and to the presence or absence of materials that may interfere between the footstep and the floor (moisture, dirt,...).

Relevant statistical data exists at Spanish national level that demonstrates the significant impact that slipperiness has on hospital-treated injuries, even more so when one remembers that falls are the main cause of accidental injury dealt with by hospital casualty departments. This fact alone justified the establishment in the Spanish National Building Code of specific safety requirements to be implemented with regard to floor slipperiness.

The afore-mentioned regulations refer to Royal Decree 314 of 17th March 2006, which approves the Technical Building Code (hereinafter CTE)⁽¹⁾. The safety requirement to combat the risk of falling is dealt with specifically in the DB-SUA Basic Document on User Safety and Accessibility.

The scope of this requirement covers floors in buildings or areas used for Public Residence, Healthcare, Teaching and Education, Retail and Commerce, Administration, and Publicly Trafficked areas, while it excludes areas with zero occupation defined in Annex SI A of the DB SI, which are classified on the basis of where they are located. For these purposes, floors are broken down according to their slipperiness into four classes depending on the slip resistance value (R_d) they obtain through testing with a pendulum tester as described in Annex A of **UNE-ENV standard 12633:2003**, in which scale C is used on test samples with no accelerated wear. The selected sample shall be representative of the most unfavourable conditions of slipperiness.

Slip resistance R_d	Class
$R_d \leq 15$	0
$15 < R_d \leq 35$	1
$35 < R_d \leq 45$	2
$R_d > 45$	3

The regulations also include the requirement that the above class category has to be maintained for the floor's entire service life. It is precisely this requirement which led to the experimental work described in this paper.

The requirement to be met by each floor, depending on its location and characteristics, is defined in Table 1.2 of the DB SUA-1.

Flooring class requirements depending on location

Location and characteristics of the floor	Class
Dry indoor areas	
- surfaces with a slope of less than 6%	1
- surfaces with a slope equal to or greater than 6% and stairs	2
Indoor areas with moisture, such as entrances to buildings from outdoors ⁽¹⁾ .	
- surfaces with a slope of less than 6%.	2
- surfaces with a slope equal to or greater than 6% and stairs	3
Outdoor areas. Swimming pools ⁽²⁾ . Showers	3

(1) Except in the case of direct access to areas with restricted use

(2) In areas where people are likely to walk barefoot and at the bottom of swimming pools where water depth is no more than 1.5 metres

2. AIMS OF THE EXPERIMENTAL STUDY

The objective of this study was to ascertain how slip resistance properties evolved in a representative series of flooring types used in different buildings at the Jaume I University in Castellon, Spain.

A campaign of readings was taken for this purpose, using a pendulum friction tester in order to study whether any trend could be detected in slip resistance properties towards greater or lesser slipperiness depending on the pedestrian traffic to which the floor was subjected, as well as the type of tile and its top surface.

That is, this paper attempts to verify whether certain types of ceramic tile develop greater or lesser slip resistance over their service life.

Studying how the Rd characteristic evolves is of great importance in order to be able to estimate or predict whether this property will develop towards a change in the tile's resistance class depending on its slipperiness and, therefore, the possibility of the floor not meeting all the requirements regarding slipperiness laid down in DB-SUA 1 of the CTE.

Therefore, once the floor to be measured has been selected, readings are taken within the same room of areas subjected to the greatest pedestrian traffic and areas in corners or under furniture in order to determine whether any variation in the Rd value (wet test) can be detected on the same floor between the area with high pedestrian traffic compared to the area with low pedestrian traffic.

A further variable to be studied is the possible influence played by the floor's state of cleanness, i.e. readings are taken before and after the floor in the test area is cleaned in order to assess whether the results of measuring using the test conditions required by the standard reproduces the floor slipperiness in actual service conditions.

In addition, readings are also taken in dry conditions on some of the test areas, i.e. without wetting the tile to be measured, in order to comply with the testing standard requirement that the response of the floor be compared in the most unfavourable conditions of slipperiness with actual floor usage conditions in dry indoor areas.

3. EXECUTION OF THE TEST CAMPAIGN

Firstly, the floors to be tested in the campaign are selected. Floors are chosen on the basis of their representativeness and their exposure to pedestrian traffic. They are also selected with the criterion of providing for a range of different floor types (porcelain tiles, glazed stoneware tiles) and top surfaces (smooth, rough, glossy, etc.), while complementary readings are also taken of other types of tiles (terrazzo tiles, natural stone).

Two test areas are chosen for each type of selected flooring in a specific area, one with high pedestrian traffic (access to entrance doors, stairways, etc.) and another considered to have low pedestrian traffic (in corners, under furniture, under stairways, etc.). This will enable any possible differences that may exist between them that depend on pedestrian traffic to be noted.

The test floors have been in service for seven or more years so that any possible difference in slipperiness between heavy-traffic and non-traffic flooring will be more obvious.

In some cases, the tests were carried out on floors at the Agustin Escardino Ceramic Technology Institute in Castellon, hereinafter ITC; in these cases, the Institute provided estimated data regarding the number of footsteps or amount of pedestrian traffic, while the zero traffic reading was carried out on spare, unlaidd floor tiles.

The following tests were performed on each test area of flooring in each building:

1. **Dry testing with no prior cleaning.** In order to perform this test, it is necessary to carry out a lengthy series of slides with the pendulum slider until the rubber adapts in order to obtain results that meet the test's repeatability standard.
2. **Dry testing with prior cleaning.** As with the previous test, it is necessary to carry out a prolonged series of slides before any relatively constant measurements can be obtained. However, before these slides begin, the surface has to be cleaned with quick-drying ethanol, making sure that when measuring starts, no cleaning materials remain on the floor that could interfere with the results of the test.

3. **Wet testing with no prior cleaning.** In this case, it is not necessary to condition the slider and the results can be noted immediately. The surface is wetted with abundant water between one slide and another.
4. **Wet testing with prior cleaning.** In this case, no prior slides are carried out and the results are noted immediately. Before the measuring process begins, the surface is cleaned with methyl alcohol and paper. It is then wetted with abundant water between one slide and another.



Test area with high traffic



Test area with low traffic

4. RESULTS OBTAINED

The following table summarises the results obtained indoors:

Table 4.1

Code	Type of tile	Top surface	Rd value when wet			
			Low traffic		High traffic	
			Not cleaned	Cleaned	Not cleaned	Cleaned
I001	Glazed stoneware tile	Rough glossy	21	22	23	23
I002	Glazed stoneware tile	Rough glossy	21	21	21	20
I003	Macael white marble	Smooth matt	9	9	11	11
I004	Glazed stoneware tile	Rough glossy	17	17	17	17
I005	Glazed stoneware tile	Smooth glossy	10	10	12	11
I006	Glazed stoneware tile	Rough glossy	10	10	11	11
I007	Porcelain tile	Smooth matt	18	17	12	12
I008	Glazed stoneware tile	Rough glossy	14	15	14	14
I009	Glazed stoneware tile	Rough glossy	25	25	19	18
I010	Glazed stoneware tile	Rough glossy	25	25	20	20
I011	Glazed stoneware tile	Rough glossy	16	16	16	16
I012	Ivory cream marble	Smooth glossy	9	10	11	12
I013	Alicante red marble	Smooth glossy	10	10	10	11
I014	Alicante red marble	Smooth glossy	9	9	10	10

I015	Terrazzo	Polished	9	9	10	10
I016	Glazed stoneware tile	Smooth glossy	10	9	10	10
I017	Porcelain tile	Smooth matt	10	10	10	10
I018	Porcelain tile	Smooth matt	16	16	14	13
I019	Glazed stoneware tile	Rough glossy	15	15	15	15
I020	Glazed stoneware tile	Rough matt	17	17	15	15
I021	Glazed stoneware tile	Rough glossy	21	24	19	20
I022	Terrazzo	Polished	14	14	20	19
I023	Porcelain tile	Smooth matt	14	14	11	11
I024	Granite	Polished	11	11	15	14
I025	Glazed stoneware tile	Rough glossy	11	11	11	11
I026*	Glazed stoneware tile	Glossy screen printed	x	14	x	13
I027*	Glazed stoneware tile	Smooth satin	x	17	x	15
I028*	Porcelain tile	Natural	x	22	x	13
I029*	Glazed stoneware tile	Glossy screen printed	x	17	x	16
I030*	Glazed stoneware tile	Glossy screen printed	x	13	x	14
I031*	Porcelain tile	Polished	x	13	x	12
I032*	Porcelain tile	Polished	x	13	x	12
I033*	Glazed stoneware tile	Matt with grit	x	20	x	19
I034*	Glazed stoneware tile	Glossy with grit	x	15	x	15

(*) Rd data and traffic flow rates provided by ITC

Table 4.2 below reveals the relationship between the results on wet and dry floors:

Table 4.2

Code	Type of tile	Top surface	Rd value when wet				Rd when dry	
			Low traffic		High traffic		Low traffic	High traffic
			Not clean.	Clean.	Not clean.	Clean.	Clean.	Clean.
I001	Glazed stoneware tile	Rough glossy	21	22	23	23	100	105
I002	Glazed stoneware tile	Rough glossy	21	21	21	20	105	111
I003	Macaël white marble	Smooth matt	9	9	11	11	64	64
I004	Glazed stoneware tile	Rough glossy	17	17	17	17	119	116
I005	Glazed stoneware tile	Smooth glossy	10	10	12	11	128	123
I006	Glazed stoneware tile	Rough glossy	10	10	11	11		
I007	Porcelain tile	Smooth matt	18	17	12	12	128	122
I008	Glazed stoneware tile	Rough glossy	14	15	14	14	115	120

Table 4.3 below shows the results obtained outdoors:

Table 4.3

Code	Type of floor	Top surface	Rd value when wet			
			Low traffic		High traffic	
			Not cleaned	Cleaned	Not cleaned	Cleaned
E001	Terrazzo	Rough matt	44	47	34	37
E002	Terrazzo	Rough matt	40	42	33	36
E003	Porcelain tile	Rough glossy	23	23	23	23
E004	Porcelain tile	Rough glossy	23	23	24	23
E005	Porcelain tile	Smooth matt	42	43	43	43
E006	Porcelain tile	Smooth matt	40	42	42	43
E007	Porcelain tile	Smooth matt	29	30	28	28
E008	Porcelain tile	Smooth matt	28	27	31	32
E009	Macael white marble	Smooth matt	15	15	17	19
E010	Porcelain tile	Rough matt	51	52	52	52
E011	Porcelain tile	Smooth matt	31	31	32	32
E012*	Porcelain tile	Rough relief	x	47	x	28
E013*	Porcelain tile	Rough relief	x	47	x	28

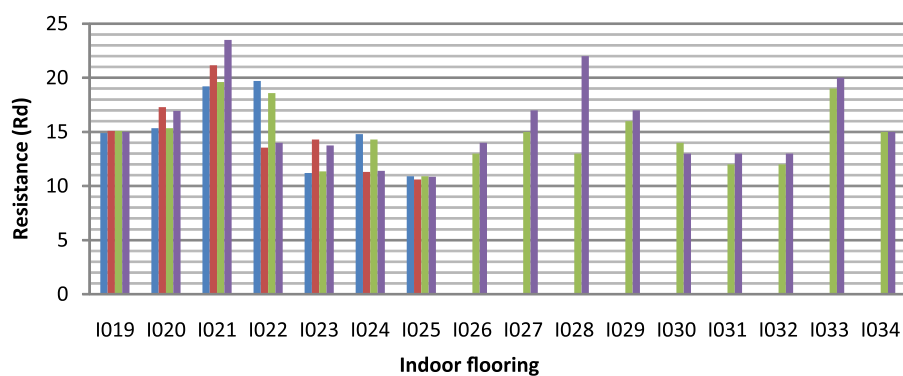
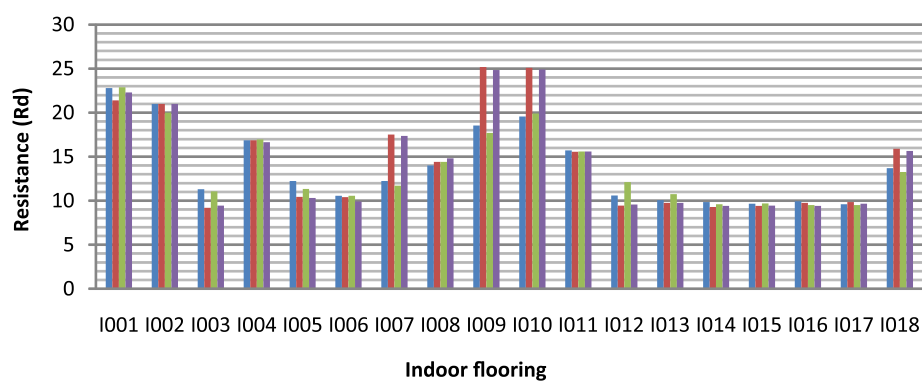
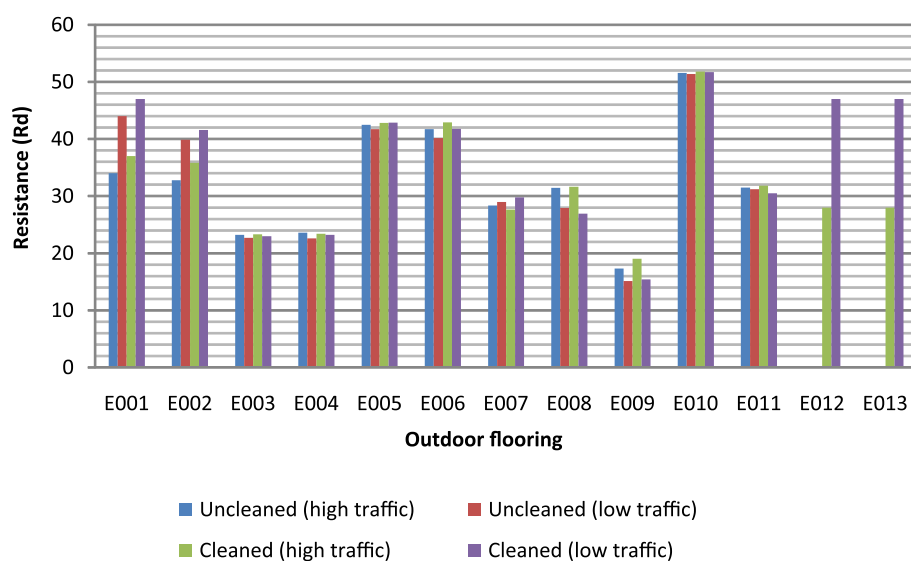
(*) Rd data and traffic flow rates provided by ITC

5. INTERPRETATION OF RESULTS

5.1. With regard to variations in slip resistance over time

One of the main objectives of this paper is to ascertain the variation that takes place over time in the slip resistance of certain tiles as a result of pedestrian traffic.

In the first stage, analysis is carried out to determine whether any Rd variation tends to occur in most floors regardless of the type of tile and top surface. In principle, as can be seen in the graphs below, no general conclusions can be drawn with regard to a general trend in which Rd diminishes over time due to the effect of pedestrian traffic during the floor's working life.

Table 5.1.a Rd of indoor flooring**Table 5.2.a Rd of outdoor flooring**

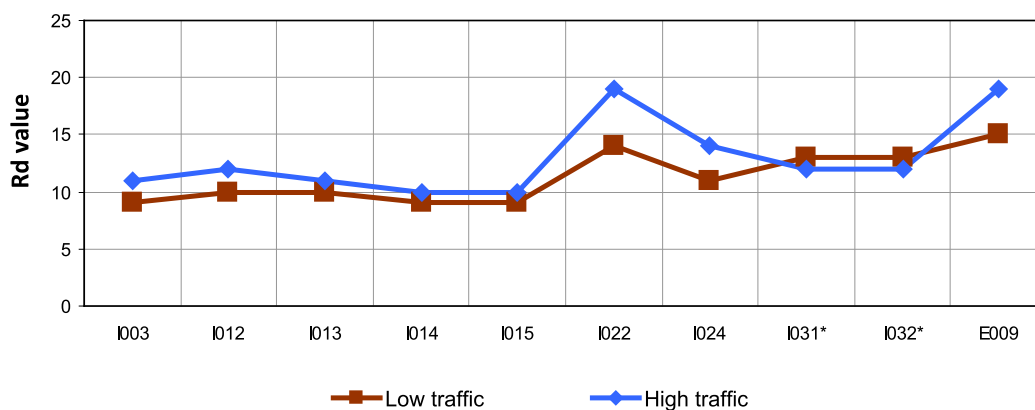
Therefore, the type of tile and top surface need to be taken into consideration in order to determine whether any actual trends exist in slip resistance (Rd) evolution.

The following graphs show the percentages of the tested flooring which reveal different trends:

- Positive trend. Slip resistance increases over time, i.e. the flooring becomes more resistant to slipperiness as a result of the wear produced by pedestrian traffic. In this paper, we shall assume this trend for floors whose test results in the most heavily transited sample show higher values than in the sample with low traffic flows.
- Negative trend. Slip resistance goes down over time, i.e. the flooring becomes less resistant to slipperiness as a result of the wear produced by pedestrian traffic. In this paper, we shall assume this trend for floors whose test results in the most heavily transited sample show lower values than in the sample with low traffic flows.

5.1.1. Polished floors

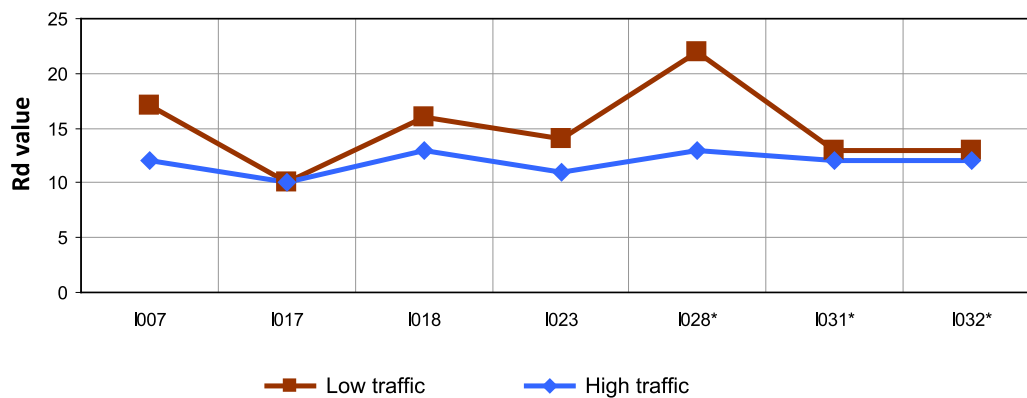
This project included studies on 10 samples of polished floors. These consisted of natural stone, terrazzo and ceramic floor types. The following graph has been drawn up with the variations in Rd (reading obtained in normalized test conditions – wet, pre-cleaned floors) observed on floors with a polished surface:



A somewhat positive trend (increased Rd) can be seen in natural stone and terrazzo floors (I003 to I024 and E009) - the increase in slip resistance reaches a maximum of 5 Rd, although the Rd value is unaltered in polished porcelain tile floors (I031 & I032).

5.1.2. Porcelain tile flooring

Most of the tested porcelain tile floors with a smooth, rough or polished surface reveal a negative trend (lower Rd), although with some singular features.

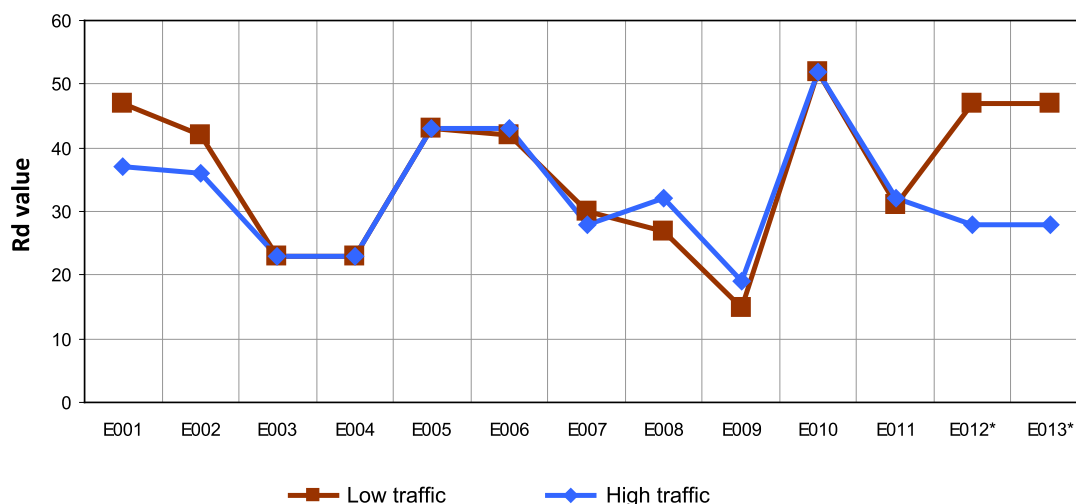


Prominent among the indoor floors of this type are:

- Smooth surface floors (I007, I017, I018, I023), which reveal a moderate decrease in Rd (they go down a maximum of 6 Rd)
- The most significant negative trend is seen in the natural surface floor I028 (dropping from 22 to 13 Rd)
- Floors with a polished surface (I031 and I032) go down by only 1 Rd.

5.1.3. Outdoor flooring

On the whole, outdoor flooring – both glazed and non-glazed – does not reveal such a clear trend as indoor floors, although special mention should be made of the following:



- Floors (E012 & E013), whose test results were provided by ITC, with a rough relief top surface, are the ones that reveal the most significant variation in Rd, dropping from 47 to 28 Rd.

- Floors with a less pronounced rough surface (E003, E004 & E010) do not undergo such a significant change in their Rd values.
- Agora floors (E005 to E008) and floor E011 all have a smooth top surface and do not reveal a clear negative trend, as their alteration over time ranges from a drop of 2 Rd to an increase of 5 Rd.
- Both the tested outdoor terrazzo floors (E001 & E002) drop between 10 and 6 Rd, unlike marble flooring (E009) with low slip resistance, which revealed a variation from 15 Rd to 19 Rd.

Therefore, it can be seen that the floors with the highest non-slip properties (with non-slip or rough surfaces) are the ones that exhibit the greatest drop in Rd value. The slip resistance of smooth-surfaced and, to a larger extent, polished floors does not vary so much as a result of pedestrian traffic.

It should be recalled that porcelain tiles are often preferred to glazed stoneware tiles for outdoor usage because of their mechanical strength and durability but that does not imply greater or lesser slip resistance, because that property is provided by the tile's relief or top surface.

The outdoor flooring tested *in situ* does not reveal a clear trend. This may be due to the fact that the areas of high and low pedestrian traffic flows are not so clearly defined, thereby preventing a distinct increase or reduction in Rd from being observed.

5.1.4. Glazed stoneware tile flooring

The non-slip properties in this kind of flooring depend on the top surface and resistance of the glaze but generally they are less negatively altered than glazed porcelain tile floors.

No significant trend or variation in Rd is noticeable (the prevailing reductions are of just 1 or 2 Rd).

One exceptional case is seen in the floor at the entrance door to the University Rectorate, references I009 and I010), where slip resistance was reduced by up to 7 Rd due to the pedestrian traffic it undergoes, which confirms that the greatest alterations take place over time. As remarked upon in the test report, tiles in entrance doorways, specifically the first row after the carpeting (where the test was performed), reveal a highly worn surface with a loss of the gloss and texture common to all the tiles. Therefore, in this particular case, any variation in slip resistance becomes even more significant.

5.2. With regard to the variance seen in the test with or without prior floor cleaning

The difference in Rd slip resistance values obtained when the floor was cleaned prior to the test compared to when it was not pre-cleaned is very small in most cases.

Surface cleanness in the floors in this test has been seen to only influence slip resistance in floors that have a large amount of surface dirt. In those cases, the build-up of dirt makes the floor more slippery and so its non-slip property is reduced.

From the results obtained on indoor flooring, the Rd value of the vast majority is seen to remain constant before and after cleaning. However, those floors where the Rd value does vary revealed a maximum variation of 2 Rd and most of them only varied by up to 1 Rd.

The outdoor flooring in our test was much dirtier than the indoor flooring, as stated in the test report. This is obviously due to:

- Outdoor flooring is not subject to the same cleaning and maintenance as indoor flooring, which means that it remains dirty for longer periods of time.
- Outdoor flooring is more exposed to pollutants such as rainwater or dust precisely because it is outside.
- Outdoor flooring has much greater roughness than smoother indoor flooring, which means that surface dirt can build up on the flooring more easily and is more difficult to remove.

5.3. With regard to performing the tests on surfaces that have not been wetted

As mentioned above, one of the objectives of this paper was to carry out the tests on a dry surface that had not been moistened.

This objective was taken into consideration on account of a foreseeable change in the legislation governing slip resistance in Spain – it is predicted that flooring with a dry Rd value >40 in dry indoor areas may be acceptable even though it does not meet the wet Rd limit.

The series of dry tests was planned for just 7 types of floor, for which the following remarks should be taken into account:

Code	Type of tile	Top surface	Wet Rd value				Dry Rd	
			Low traffic		High traffic		Low traffic	High traffic
			No clean.	Pre-clean.	No clean.	Pre-clean.	Pre-clean.	Pre-clean.
I001	Glazed stoneware tile	Rough glossy	21	22	23	23	100	105
I002	Glazed stoneware tile	Rough glossy	21	21	21	20	105	111
I003	Macaël white marble	Smooth matt	9	9	11	11	64	64
I004	Glazed stoneware tile	Rough glossy	17	17	17	17	119	116
I005	Glazed stoneware tile	Smooth glossy	10	10	12	11	128	123
I006	Glazed stoneware tile	Rough glossy	10	10	11	11		
I007	Porcelain tile	Smooth matt	18	17	12	12	128	122
I008	Glazed stoneware tile	Rough glossy	14	15	14	14	115	120

- For this type of test, the rubber slider has to adapt to the surface which it is to measure in order for the readings to reach a certain degree of stability. This means that after levelling the apparatus and adjusting the slider sweep length, on many occasions up to 30 slides of the pendulum have to be performed before the readings start to stabilise. This operation should always be done when measuring new floors and to a lesser extent if the position of the pendulum is changed when measuring the same floor.
- The values obtained on the first slide go down gradually until the readings can be considered stable and such stable values can be up to 35 Rd lower than the first test reading.
- The rubber slider wears quickly, not just as a result of the number of initial slides required for the readings to stabilise but also due to the heavy friction it undergoes when the slider comes into contact with the surface in the absence of the lubrication provided by water.
- The surface of the slider in contact with the floor appears to be textured during the test.
- Any worn rubber shavings from the slider should be removed from the floor surface to ensure they do not interfere with the reading.
- The values obtained with a pendulum friction coefficient meter in these first tests ranged between 60 and 130 Rd but with no clearly defined trend between heavy-traffic and no-traffic areas.
- Measurement repeatability without changing the position of the apparatus is good once measurement has stabilised.
- Measurement repeatability as soon as the position of the apparatus is changed on the same floor is no longer good. The readings obtained between different areas on the same flooring reveal very different stabilised values.

- Reproducibility is insufficient for a test of these characteristics. It is difficult to reach the same results with different rubber sliders and even the same slider gives different results depending on the roughness micro-profile to which the rubber has adapted in the test prior to the one it is performing. Attempts were made to reproduce the readings from previous days on indoor tiles at the same temperature but they turned out to be very difficult to achieve.

The results obtained from dry tests gave very high R_d readings – in all the ceramic tiles included in the test, the results were over 100 R_d . Therefore, if this new limit were to be included for dry indoor areas in Spanish regulations, it would seem that the rules are to change from a very stringent limit (wet measurements) to a very lax limit for measurements on dry floors.

5.4. With regard to fulfilment of the requirements laid down in DB SUA-1 of the CTE

Even though all these floors were laid prior to the Technical Building Code coming into force, it is nevertheless of interest to compare the R_d values obtained with those that are currently required by the CTE for flooring in identical locations and characteristics.

In our case, regardless of whether the tests were made in areas with high or low pedestrian traffic and with prior floor cleaning or not, only 2 indoor floors and two outdoor floors meet current CTE requirements, which account for 7.4% and 14.3% respectively of all the types of flooring in the test.

At the same time, the Occupational Hazard Prevention department at the Jaume I University was consulted and confirmed that, although some complaints have been heard, no records are known of falls taking place on indoor flooring. On the contrary, measures did have to be taken on some of the outdoor flooring to improve its slip resistance in the event of rain, although no accidents involving human injury are known to have occurred.

6. FINAL CONCLUSIONS

Briefly and with the limitations inherent in the small number of flooring types studied, the following final conclusions can be made:

- No general conclusion suggesting that slip resistance is reduced over time as a result of pedestrian traffic can be made.
- Natural stone and polished terrazzo floors reveal a greater tendency towards increased slipperiness than polished porcelain tile floors.
- Natural smooth porcelain tile floors demonstrate a lower negative tendency, i.e. increased slipperiness over time compared to tiles with rougher surfaces.

- In outdoor paving, some top surfaces with rough relief reveal a significant loss of slip resistance.
- In general, glazed flooring preserves its non-slip properties better than un-glazed floors.
- The influence of cleaning on the floors in the test was seen to be minimal in most cases. It was only obvious in those floors with a very dirty surface and made them less slip-resistant.
- On the basis of the small variations noted as a result of usage, it would appear that floors with an Rd value well below the value limits set by the CTE should be chosen.
- With regard to slipperiness testing on dry floors, despite the reproducibility problems it poses, the results obtained on ceramic tiles are over 100 Rd.
- Glazed stoneware tiles are seen to have better dry performance than marble flooring.
- Practically none of the floors in this test, which were fitted prior to the CTE coming into force, would fulfil all the slip resistance requirements if made applicable to them. However, no problems due to accidental slips on indoor floors are known to have taken place to date.

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