CI/SfB F
March 2000

Flooring, paving and setts

IP 10/00

Requirements for safety in use

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information paper

This Information Paper summarises a programme of research that included studies of the slip resistance of products in use, the wear and abrasion of materials, and the overall durability when subjected to vehicular and pedestrian traffic. The project focussed on natural stone products but also included a comparison of similar products. The work was carried between 1995 and 1997 in order that the results were available to CEN/TC 178 Working Group 2 during the drafting of the European Standards for natural stone paving, setts and kerbs.
This Paper will be of interest to architects, specifiers, facilities managers, local authority highways engineers, contractors, and manufacturers and suppliers.

Background and research objectives

People slip because the frictional force between the shoe and the floor is too small to resist the horizontal component of the force applied to the floor. The primary objective of the research described in this Paper was to assess the effectiveness of current and future requirements for minimising the risk of pedestrians slipping on flooring, paving and setts manufactured from natural stone.

Secondary objectives included:

- reviewing dynamic and static slip/skid tests;
- predicting the effect of pedestrian traffic on slip/skid resistance;
- determining the effect of wear and weathering on surface finish;
- comparing test results for a range of flooring and paving materials.

The areas of study were linked directly to the requirements of the Construction Products Directive and the Mandate for Flooring which was being drafted at the same time as the research was being undertaken. The current versions of the European Standards for Natural Stone Paving, Setts and Kerbs (EN 1341, EN 1342 and EN 1343) were prepared as 'market standards' but these are now being revised under the Mandate M117 given to CEN by the European Commission and the European Trade Association relating to the CE marking of these products.

A number of clauses (Table 1) in these European Standards have been drafted to meet the requirements of the Mandate given under the EU Construction Products Directive (89/106). Compliance with these clauses confers a presumption of fitness of the construction products covered by those Standards for their intended uses.

All of the characteristics shown in Table 1 are related to safety: in particular to the possibility of slipping or tripping.

Other characteristics that are important to the industry may also be included in the Standards, provided they are separated from the CE marking characteristics and provided it is made clear that the CE marking does not

Table 1 Relevant clauses in European Standard EN 1341

Requirements/characteristics from Mandate M117	Requirement clauses in EN	Mandated levels or classes
Breaking strength	4.3	None
Slipperiness	4.5	None
Skid resistance	4.5	None
Durability	4.2	None
	4.4	None

apply to them. In the case of natural stone paving and setts, another key characteristic is abrasion resistance – that is, the rate at which the unit will wear in normal use.

Why do people slip?

When a person, with his or her leg inclined at an angle to the vertical, places the foot on the floor, a force is applied to the floor, which may be resolved into a vertical component (V) and a horizontal component (H). To walk without slipping, the horizontal component must be always less than the frictional force (F) between the shoe and the floor; therefore for safety:

$$F > H$$

where $F = \mu V$ and μ is the coefficient of friction (which depends upon the nature of the shoe and materials), and any third body interference such as water, dust and polish.

It follows that, for safety:

$\mu V > H$, or

$$\mu = H/V$$

Conversely, if H/V exceeds the coefficient of friction, a slip will occur, but whether that leads to a fall depends on many other factors.

Coefficients of friction

Work at BRE has established that the average coefficient of friction produced when walking was between 0.16 and 0.22, depending on the direction of movement and the sex of the person. It was initially found that only one person in a million was likely to exceed a value of 0.4, but these data were later refined to those shown in Table 2 below.

Measuring slip resistance

Methods of measurement

While many instruments have been designed for measuring the slipperiness of flooring, the TRL pendulum tester has generally found most favour, and this is the technique used by the UK Slip Resistance Group [2] and most CEN Technical Committees concerned with external paving and roadways. Essentially this technique measures the frictional resistance between a slider mounted on the end of a pendulum and the floor surface.

The Tortus is a more recent apparatus. In many respects it appears to be a better way of assessing the slip resistance of a floor surface as it gives a direct reading of the lateral force required to drag the slider, to which is applied a constant vertical load, across the floor. This slider, which is like a small button, can be fitted with shoe soling or other material. The criterion of 'failure' for the floor surface being tested is BRE's figure of 0.4 or more.

However, during a number of research programmes, it rapidly became apparent that the readings between the two types of machine did not correspond. In general the Tortus gave lower values than the pendulum for the coefficient of friction in the dry while the pendulum gave lower values than the Tortus in the wet. For obvious reasons wet readings are usually the more critical. While the pendulum test often indicated that a surface was dangerous, the test with the Tortus gave a safe result. As a result, manufacturers tend to support the Tortus test method and independent assessors representing people who slip on manufacturers' products prefer the pendulum test.

Table 2 Coefficients of friction between foot and floor [1]

Risk	Straight walking	Turning:left foot	Turning:right foot
1 in 1,000,000	0.36	0.40	0.36
1 in 100,000	0.34	0.38	0.34
1 in 10,000	0.29	0.34	0.33
1 in 200	0.27	0.31	0.32
1 in 20	0.24	0.27	0.29

Table 3 Summary of slip and abrasion resistance test results

Stone name	Stone type	Slip resistance value	Wide wheel abrasion resistance (mm)	Breaking strength (MPa)
Rockingstone	Sandstone	78	15.7	12.0
Blue Pennant	Sandstone	71	19.0	33.5
Kirkstone Sea Green	Slate	10	19.5	Not determined
Crosland Hill	Sandstone	75	19.6	15.0
Red Lazonby	Sandstone	76	19.6	5.9
Portland Whit 1	Limestone	83	21.0	8.0
Dursand	Sandstone	74	21.1	5.0
Portland Curf	Limestone	78	21.7	11.9
Birchover	Sandstone	75	22.1	9.2
Baxtonlaw	Sandstone	73	22.1	24.9
Portland Roach	Limestone	85	22.5	6.5
Kirkstone Silver Green	Slate	14	22.6	Not determined
Portland Whit 5	Limestone	82	22.6	8.6
Stanton Moor	Sandstone	79	22.6	8.2
Portland Base 1	Limestone	74	22.7	7.3
Portland Blue	Limestone	36	23.0	13.8
Doddington	Sandstone	78	23.2	3.4
Portland Whit 2	Limestone	77	23.3	7.6
Portland Whit 3	Limestone	80	23.4	7.6
Perrycot	Limestone	79	23.7	7.6
Springwell	Sandstone	Not determined	23.7	7.0
Talkin Fells	Sandstone	94	23.9	18.5
Portland Cap	Limestone	60	24.3	12.5
Portland Whit 4	Limestone	84	25.6	6.2
Portland Base 2	Limestone	81	26.2	7.7
Westwood	Limestone	84	26.2	3.4
Dunhouse Buff	Sandstone	79	26.9	9.5
Stoke Ground A	Limestone	80	28.2	5.4
Stainton	Sandstone	80	29.0	5.9
Darney	Sandstone	77	29.2	3.6
Baxter	Sandstone	77	30.3	3.2
Monks Park	Limestone	83	33.1	4.6
Red St Bees	Sandstone	75	33.4	8.8
Stoke Ground B	Limestone	80	34.5	3.7
Red St Bees 2	Sandstone	79	34.9	9.3

Findings from the research programme

A total of 34 limestones, sandstones and slates from the UK were tested for slip resistance using the pendulum test method described in EN 1341 on wet specimens. All of the samples had surface finishes typical of those supplied on finished products.

The results, summarised in Table 3, confirmed that stones with a honed or sawn finish will usually have slip resistance values (SRVs) greater than 70, but those with a more polished finish may easily have values less than 40. The slip resistance of Perrycot, for example, can change from 79 to less than 30 as the surface is honed and polished to a smooth finish. These findings are consistent with past experience which has shown that, in general, the more polished and smooth a stone is, the more likely it is to be slippery, particularly when wet.

Measurements made in other research programmes have shown that for a stone to have a polished finish it needs to have a surface roughness of less than 2 μm. Research has also shown that if surface roughness is greater than 4 μm, the surface will usually have sufficient texture to have a SRV greater than 20. However, there is some evidence that a stone with a rough surface (eg a roughness of 0.5–1.0 mm) can still be slippery if the surfaces of individual grains become polished. This suggests that it may be important to establish both the macro and micro textures of some stones.

Research was also undertaken on the effect of the temperature at which testing is carried out on slip resistance. The earlier drafts of the European Standards allowed testing to be carried out at between 15 °C and 25 °C. The results showed a clear relationship between SRV and temperature, but only for stones with a polished finish. For example, the slip resistance of specimens of Cornish Silver Granite ranged from more than 100 at 24.5 °C to around 50 at 12 °C. The revised version of the test method now requires the measurements to be made within the temperature range of 18 °C and 22 °C. This greatly reduces the spread of results though at 18 °C there is still some evidence that the results can be affected to a significant degree.

Guidance in relation to results achieved

In the late 1960s and 1970s, much work was done by the Greater London Council (GLC) Scientific Branch using the pendulum apparatus at accident sites. It published the following assessed values of resistance to slipperiness and related categories of safety [3]:

SRV using TRL pendulum	*Safety category*
≤ 19	dangerous
20–39	marginal
40–74	satisfactory
≥ 75	excellent

These SRVs, sometimes called slipperiness coefficients, are read directly from the pendulum scale and are about 100 times greater than the equivalent coefficients of friction. The values have been used widely in assessing the slipperiness of floorings. However, as the rubber slider used with the TRL pendulum was different to that used in current tests, the results are not now directly applicable. The rubber chosen for the CEN Standards on paving is very similar to the one used in this research and so BRE's results are comparable, effectively, with the European criteria.

In the late 1980s, criticism of the rubber slider on the TRL pendulum tester led to the development of the '4S rubber' which has now been adopted in the draft guidelines recommended by The UK Slip Resistance Group [2]. The 4S slider can be used on normal internal flooring materials that are not enhanced to provide additional safety for hazardous conditions. These draft guidelines provide the following values for assessing floors.

4S pendulum value	*Potential for slip*
< 25	High
25–35	Moderate
35–65	Low
> 65	Extremely low

Further guidance is also presented in the 1998 CIRIA Report 184 [4]. This also recommends the pendulum tester for assessing the slip resistance of a terrazzo floor and indicates that the SRVs should not be less than 40 in either wet or dry conditions. It also acknowledges that service conditions will be a very important aspect of test results.

The slip resistance of a surface may change with use, either becoming more slippery as a result of natural polishing or less slippery as a result of abrasion and roughening of the surface. The development of a test that recognises the 'durability' of a surface is being considered by a Working Group of CEN/TC 178, but no test has been agreed yet. The British Standard, BS 7932, provides a basis for calculating a 'polished paver value' that can be used in slip resistance tests; this involves artificially abrading the surface to mimic the effect of foot or vehicle traffic. Unpublished data from CEN/TC 178 indicates that the SRVs of stones change by around 10 to 20 units in use and in the polished paver test: for example, a maximum reduction in slip resistance from 75 to 55.

Measuring abrasion resistance

Methods of measurement

Abrasion is wear caused by fine solid particles. Forms of wear other than abrasion include cutting, adhesive, corrosive, and surface fatigue. Abrasion and cutting are usually considered the most significant forms of wear as far as flooring is concerned.

Wear is most severe where pedestrian traffic changes direction and where people move in confined areas: for example, at ticket barriers.

Traditionally two types of test have been used to determine abrasion resistance.

- The first involves pressing the surface of a specimen flooring material against an abrasive wheel for a specified number of rotations, removing a thickness of the specimen surface. The abrasion resistance is determined by measuring the weight loss or change in thickness. Examples of this type of testing are the American Amsler test and the German Böhme test.

- The second type of test involves pressing the surface of a specimen against the edge of an abrasive wheel that cuts a groove into the surface. Abrasion resistance is determined by measuring the width, depth and length of the groove. An example is the French Capon test.

Discussions within CEN/TC 178 led to adoption of the French Capon method for European testing, but there was disagreement on the width of the metal wheel: narrow (10 mm) or wide (70 mm). It was decided that the wider wheel was more appropriate for natural stone as it was less likely to be affected by inhomogeneities.

Findings from the research programme

The results of testing the 35 stones used in this research are shown in Table 3. Initially there had been some concerns regarding the ability of this type of test to differentiate between 'hard' and 'soft' stones. The table shows that there is a reasonable spread of results – covering at least a factor of two – with stones that are traditionally seen as hard wearing (eg Crosland Hill York Stone) having the highest resistance to abrasion.

Tests were also carried out to look for a correlation between the 'narrow' and 'wide' wheel tests. The results (Figure 1) show that although the two methods are based on similar principles, the results are not easily compared.

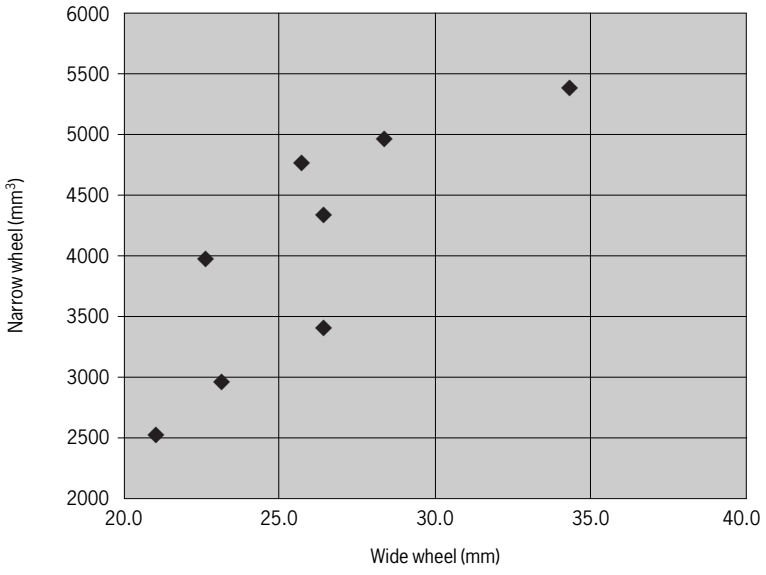

Figure 1 Comparison between abrasion resistance measured using the narrow and wide wheel tests

Table 4 Exposure of floorings to wear during service life

Class of use	Number of pedestrians	Number of journeys across floor each day	Number of days per year	Service life expectancy without significant wear (years)	Approx total of number of pedestrian journeys
Intensive (eg airport, shopping mall)	70,000+	1	350+	20	500,000,000
Medium (eg office building)	500	2	250	20	5,000,000
Low (eg individual residence)	4	4	350+	10	50,000

Guidance in relation to results achieved

At present there is no published guidance on interpretation of the wide wheel abrasion test. The French standard on natural stone (XP B 10-601) [5] provides guidance for the Capon test and suggests that usage can be divided into three classes: individual, collective moderate and collective intense. Unfortunately it is not possible to transfer the guidance directly to the wide wheel abrasion test as wheel and abrasive material are both different in each test. However, there is data for a single stone that was tested by both methods. This result suggests that the division between 'individual' and 'moderate' could be around 31 mm but this figure appears to be a little on the high side.

The draft European Standards for concrete paving slabs and blocks have recommend that the dividing line between 'light' and 'intensive' traffic should be 23 mm. The results in Table 3 seem to confirm that this is a reasonable and realistic dividing line provided that division does not be come too absolute. Using these numbers the following guidance is proposed.

Abrasion resistance value	*Suggested usage*
<23	Intensive use (eg shopping malls)
23–30	Moderate (eg office buildings)
>30	Individual (eg houses)

However, this guidance does not, at present, take into account the required service life of the surface, nor the cleaning and maintenance regime.

It is now possible to begin to estimate the link between service life and expected abrasion and so the following classification is suggested†.

- Less than 23 seems to be suitable for heavily trafficked areas. This is approximately equal to 500 million pedestrian journeys during the service life of the floor.
- Between 23 and 30 is likely to be satisfactory for offices, etc (but not shops, stations etc). This is approximately equal to 5 million pedestrian journeys during the service life of the floor.
- Greater than 30 is probably restricted to houses or apartment blocks. This is approximately equal to 50,000 pedestrian journeys during the service life of the floor.

The total number of pedestrian journeys during the service life of the floor is based on the estimates shown in Table 4.

Wear is unlikely to be graded evenly across a floor. There will be greater wear at turning points; at places where the movement of people is constrained (eg through ticket barriers); and at commonly used pathways (eg from a door to a lift).

† These classes are based on limited data and must be considered preliminary estimates. The total number of pedestrians is also a first estimate and is based on data from a number of sources including measurements made in situ.

Measuring breaking strength

Methods of measurement

The breaking strength of natural stone paving and kerbs is usually determined by a conventional three or four point flexural strength test, while the breaking strength of setts is determined by measuring the unconfined compressive strength. The measurement of strength only becomes important when the unit is not fully supported and particularly where the units are large. Guidance on laying natural stone slabs will be found in BS 7533-4.

Findings from the research programme

The results from the testing of the 33 stones in the programme are given in Table 3. The stones tested show a wide range of results: from 3.2 MPa to 33.5 MPa.

Table 5 Breaking loads and typical uses for natural stone slabs (based on classes in EN 1341)

Class	Breaking load (min) kN	Typical use
0	No requirement	Decoration
1	0.75	Slabs bedded in mortar, pedestrian areas only
2	3.5	Pedestrian and cycling areas; gardens, balconies
3	6.0	Occasional car, light vehicle and motorcycle access areas; entrances and thresholds to garages
4	9.0	Malls, market places etc occasionally used by delivery vehicles and emergency vehicles
5	14.0	Pedestrian areas often used by heavy lorries
6	25.0	Roads and streets, petrol station forecourts

Guidance in relation to results achieved

The strength of a slab can be determined by calculating the minimum breaking load P (kN) from the equation:

$$P = \frac{R_{tf} W t^2}{1500 L \times 1.6}$$

where:

R_{tf} is the flexural stress (MPa)
W is the width of the slab (mm)
t is the thickness of the slab (mm)
L is the length of the span (mm)

The value 1.6 is included as a safety factor. All dimensions are working dimensions and the result of the equation is valid up to a maximum of 900 mm.

Alternatively, the required slab thickness t for any given class of use can be calculated from the equation:

$$t = \sqrt{\frac{1.6 \times 1500 L P}{R_{tf} W}}$$

Suggested breaking loads for different classes of use are given in Table 5 or may be calculated where more detail is necessary.

Conclusions

The research programme has shown that the test methods proposed for use in the European Standards for paving, setts and kerbs seem to give realistic and reliable results when applied to a range of UK stones.

The slip resistance of most of the stones tested was sufficiently high for them to be classed as safe. However, stones that were finely honed or polished were likely to be unsafe when wet. The guidance on interpreting the results of earlier research programmes still seems to be valid and this allows clear statements to be made concerning any {health and} safety problems that are likely to arise with a newly laid stone surfaces. However, at present, there is no agreement on a test to artificially age a stone in service, and so it is more difficult to determine the likely future performance of paving or setts; current information suggests, though, that most sawn or honed stones will remain 'safe'.

The wide wheel abrasion test seems to be capable of discriminating between 'harder' and 'softer' stones, but, currently, there is only limited data available to interpret the results. A possible classification has been put forward based on currently available information.

Overall, it is clear that a wet new stone with a slip resistance value greater than 60 should be safe, and will remain safe even if it becomes polished in service, provided that it is kept free from deposits that could increase its slipperiness (eg dust, oil or biological growths). If the abrasion resistance is less than 23, it is also likely to wear well over many years. The flexural strength and the expected load can be used to determine the thickness and size slabs.

It is quite possible to use stones that have a lower slip resistance or more limited abrasion resistance but it will then be necessary to consider use and conditions in more detail.

- Will it get wet?
- Will it become polished with use?
- How many people will walk over it?
- How long is the surface expected to last?

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British Standards Institution

BS 7533-4:1998. Pavements constructed with clay, natural stone or concrete pavers. Code of practice for the construction of pavements of precast concrete flags or natural stone slabs

BS 7932:1998. Method for determination of polished paver value (PPV)

European Standards

EN 1341:1999. Slabs of natural stone for external paving – Requirements and test methods

EN 1342:1999. Setts of natural stone for external paving – Requirements and test methods

EN 1343:1999. Kerbs of natural stone for external paving – Requirements and test methods

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ISBN 1 86081 372 0