On *slippery* ground

Construction Design & Management regulations are putting the onus on designers to make sure floors are safe. If this industry cannot show stone is safe, it could lose out to other materials. Barry Hunt, from consultants Stats, examines the issue.

Moisture or grease can turn a safe floor into a slippery floor.

WHEN SOLICITORS start advertising their services specifically to people who have tripped or slipped, it is time to take a second look at flooring and paving. Such adverts are now appearing on the radio, in newspapers and on the Internet. So what can you do to protect yourself and your clients from receiving an unwanted call from a solicitor?

The answer is not quite as straightforward as it might be because there are no British Standards covering stone floors. There is just a jumble of advice that has evolved over the years.

The Construction Design & Management (CDM) regulations have added a new edge to the problem of stone floor safety for designers because it makes them responsible for all areas over which they have an influence, which could include floor safety. But who sets the criteria for what is safe?

If the stone industry sits back and waits, the courts will decide. This could be devastating. It could make polished stone floors a thing of the past, even though most polished stones provide excellent walking surfaces – except when they are wet, which is why they are usually confined to internal areas.

Are such floors to be penalised on the basis of the slightest risk of an accident occurring when undergoing cleaning or someone spilling a cup of tea that does not get mopped up immediately?

Accidents will happen, no matter what precautions are taken. But it is up to the designer of a floor to increase the odds against them. To do that, we must look at how accidents happen, starting with the way we walk.

In order to move forward you swing a leg out in front of you, which puts you off-balance and out of control until the foot touches ground again. When it does so, it should gain a grip and allow the other leg to be swung forward.

Walking upright on two legs involves the continual fine tuning of an essentially unstable process. That process can be interrupted if something throws a person just a little more off-balance than expected. The result can be slipping, stumbling or tripping.

Slipping is the result of an unexpected loss of grip by the foot, stumbling the unexpected regain of grip when a foot is sliding forward, and tripping the result of an unexpected encounter with an object which stops the progress of the leg moving forward.

There are, then, four factors to be considered in designing a safe floor:

- friction between the foot and the surface
- rapid changes in the surface that alter the friction
- rapid changes in the level of the surface
- the human factor.

Of these four factors, the two easiest to resolve are the rapid changes in the surface friction or the level.

Rapid changes in surface roughness may be caused by placing polished stone next to stone with a rougher finish (honed, chiselled, flame-finished, riven, etc). Different finishes are often used for aesthetic reasons and to delineate different areas.

Rapid changes in the level of the surface are a bit more of a problem as the earth is not flat and between two points there may be slopes and steps. Even the supposedly flat surface of a floor may not be so flat. Adjacent stones may not be flush and lips of only one or two millimetres can be enough to halt the progress of a moving foot.

Friction between the feet and the floor surface is more difficult to control as it relies to some degree on the human factor. The main areas of consideration are:

- macro-roughness
- micro-roughness
- contact area
- inertial weight
- angle of contact
- momentum
- ability of the contact surface or foot to change shape
- presence of a lubricant
- the existence of structures to reduce the lubricant effects
- material sheer
- temperature
- deposits, including biological growths

Macro-roughness is the roughness visible to the ⇨

naked eye – ie a textured, rather than polished, finish. However, this can be misleading. If the stone is smooth at the micro level, there may be little difference in slip resistance between a textured and a polished surface.

One common example is flame-textured granites and other hard stones. The finished surface, although initially rough, can rapidly lose its many sharp edges as they are knocked off by people walking on it. This is relatively easy as many of the edges are actually loosened by the flame texturing process. The stone may soon be left with a wavy surface that provides little resistance to slip in wet conditions.

Sandstones, on the other hand, can be flat and smooth while maintaining a high degree of slip resistance. The reason is their micro-structure. They comprise grains set within a matrix and are porous.

The matrix typically wears at a slightly greater rate than the grains and a roughness is maintained. The pores also help to maintain this roughness by creating numerous small depressions. Additionally, as sandstone is abraded, the grains standing most proud will eventually be knocked out leaving a small depression.

Contact area is very much a human factor, either through having differently sized feet or the choice of footwear, such as high, pointed heels that reduce the contact surface. The greater the contact surface the greater the resistance.

Inertial weight is principally the size of a person. Someone weighing 50kg will be twice as easy to push along the ground as someone with the same contact surface who weighs 100kg.

The angle of contact relies on the slope of the floor. Standing on a flat surface a body will be at rest but if the

Above. An uneven edge can bring the forward progress of a foot to a sudden halt, causing a trip.

Right. Even floors which are not polished have to be laid flat and smooth, like this Corncockle sandstone example at the award-winning Tower of Lethendy, in Scotland.

surface angle is increased there will come a point when the body will eventually slip from the surface. The more slippery a surface the lower the angle of slope that is required for a body to begin to slip.These principles are those employed by the German ramp test for slip resistance (see below).

Momentum is a major factor in walking. If the force of this momentum is greater than the frictional resistance of the floor, then you can slip. This is best demonstrated by a person who is running. They have more momentum and to stop or turn becomes more difficult (or less controllable).

The ability of a foot to change contact shape is important. Rubber shoes can bend and mould with the overlying weight of the person into the floor surface creating greater interlock and thus greater resistance to slipping. Metal shoe heels are a major problem as they cannot adapt to the surface and give practically no grip.

Dry surfaces, even when polished, can provide excellent slip resistance. Add a lubricant such as a little water or oil, however, and they can become slippery. Inside, polished floors can be kept dry. Outside, it is harder to keep paving dry.

One of the worst combinations is a wet surface where a little oil has been spilt. Even the roughest surfaces can become slippery as the oil does not mix with the water and aquaplaning over the surface becomes a distinct possibility.

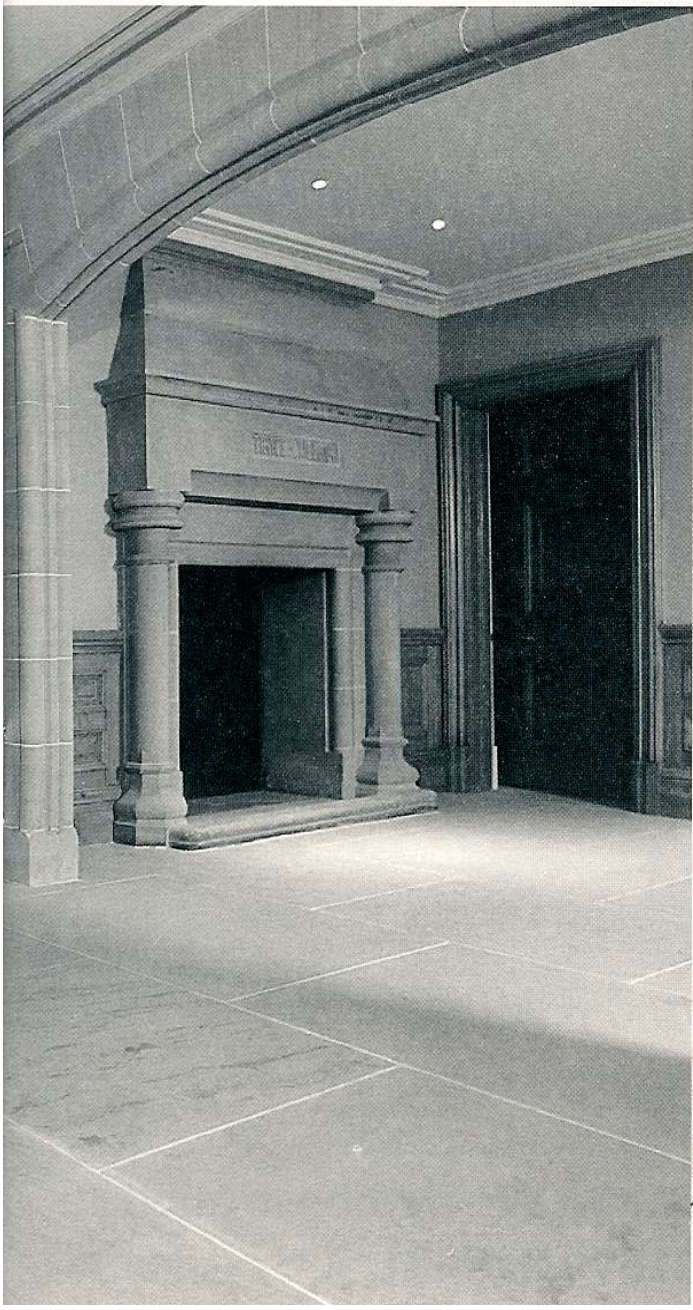
The matter of spillage should be taken seriously in floor design, especially in areas around swimming pools, for example, and areas where foods are bought, sold and eaten, which may have both regular spillages and frequent cleaning.

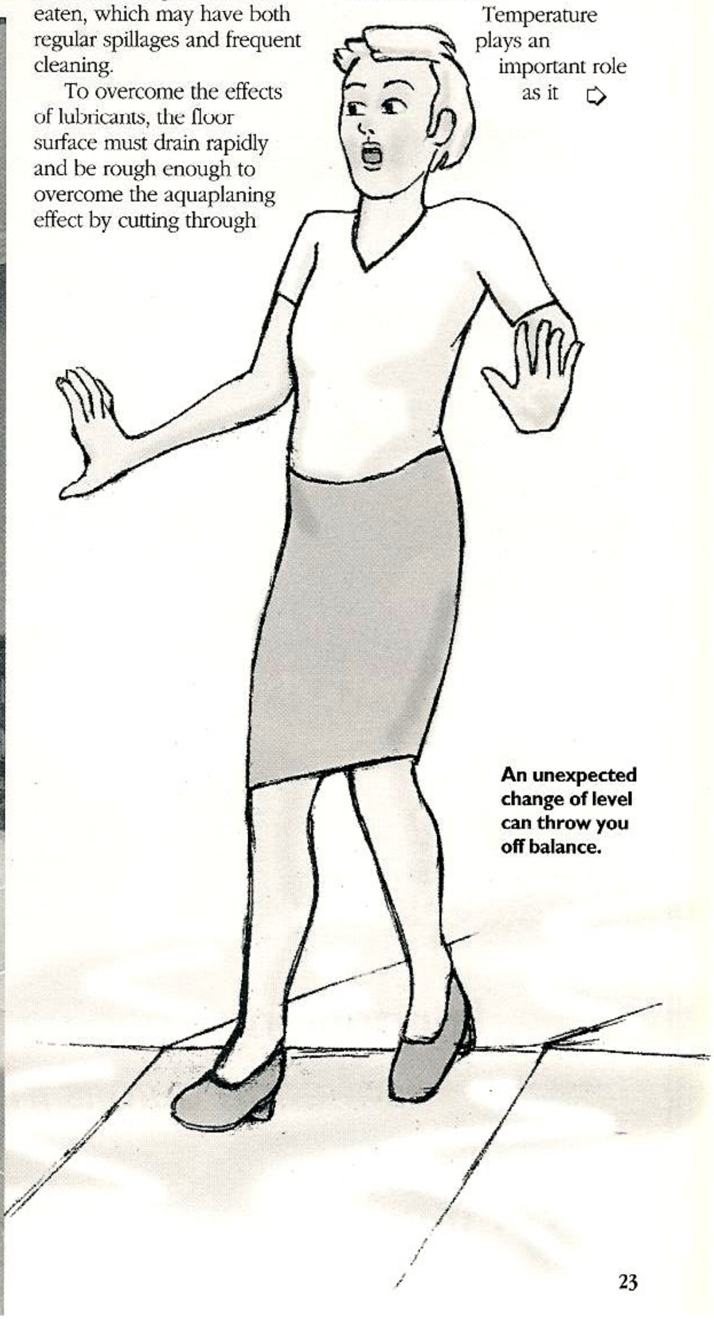
To overcome the effects of lubricants, the floor surface must drain rapidly and be rough enough to overcome the aquaplaning effect by cutting through the surface tension of the lubricant.

Porous stones, such as sandstones and limestones, are good at removing surface water and thus the potential for aquaplaning.

Material sheer is probably best demonstrated by a skidding car. If the car has a lot of momentum and the brakes are applied quickly the wheels may lock and the car will begin to skid, leaving a trail of rubber. Tearing rubber from a tyre takes energy, which slows the car down but there is no control in a skid.

Temperature plays an important role as it ⇨

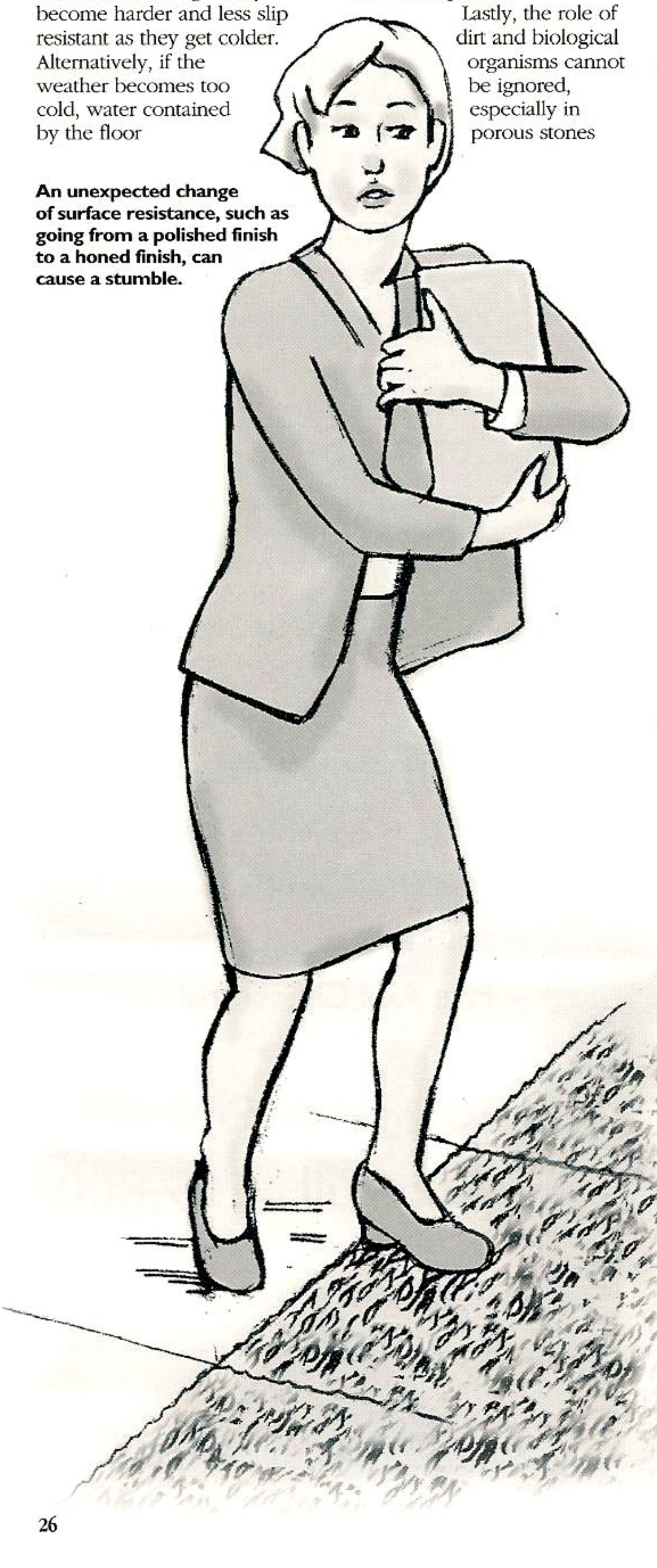




An unexpected change of level can throw you off balance.

can greatly alter the properties of materials such as rubber shoe soles making – they become harder and less slip resistant as they get colder. Alternatively, if the weather becomes too cold, water contained by the floor may turn to ice presenting a completely different surface to the one expected.

Lastly, the role of dirt and biological organisms cannot be ignored, especially in porous stones used externally. Dirt can fill the natural pores and cavities and make the surface slippery.



An unexpected change of surface resistance, such as going from a polished finish to a honed finish, can cause a stumble.

Mosses, lichens and other organisms may find a porous stone that retains moisture a rather pleasant haven in low traffic areas. Green organic films can reduce a slip resistant surface to one that is dangerously slippery, highlighting the importance of maintenance.

Is there a perfect flooring stone?

There is no floor surface, stone or any other, that will maintain itself and provide continued slip resistance. That is not a position which can be resolved by simply setting a minimum requirement for a floor as the factors involved are too many and, ultimately, out of reasonable control. A floor surface will only perform to its level of maintenance over and above its intrinsic qualities.

So what are those intrinsic qualities? One big problem is that there is no general agreement about the most appropriate methods for determining them.

Direct slip resistance has been determined for many years by the pendulum arm apparatus developed by the old Transport & Road Research Laboratory (TRRL), now simply the Transport Research Laboratory.

The test was originally devised for assessing the slip resistance of road surfaces. The test involves a standard rubber of standard size, travelling at a standard speed a standard distance across the surface of interest.

This movement is achieved by a pendulum swing. The retardation in the swing is used to assess the slip resistance. The method was adopted by the American Society for Testing & Materials (ASTM).

The trouble is, the test is relatively easy to abuse. Samples submitted are often in various states of finish and the results are then used as if they applied to a polished stone floor.

It was suggested that the pendulum arm test be used for the European standard. However, it has not been accepted and there is still no consensus about what test should be used and no standard.

Of the tests available, I prefer the German ramp test. However, it is both complicated and expensive to run. Also, it cannot be carried out away from the laboratory, so if an already fixed surface is to be tested, part of it has to be lifted and taken back to the laboratory.

The ramp test involves a person standing on a sample of the material being tested in a standard pair of shoes. The sample is gradually raised until the person slips. Allowances are made for the person's weight and they are blindfolded so there is no conscious attempt to adjust the body angle which may affect the result. The higher the angle the ramp achieves, the higher the slip resistance.

Some people prefer the higher-tech method of measuring the reflectiveness of the surface of stone. There are a variety of reflectometers on the market that may shine different forms of light, including laser, on to a surface and then measure the reflectance and dispersion to provide a measure of roughness.

These machines have a problem on the surface of stone in that the crystals in the stone may absorb some of the light or reflect it internally to provide a false reading. Machines that work with a low angle beam of light will have less light absorbed, but textured surfaces may cause shadowing at low angles that, again, will affect the results.

If there is little agreement on how to determine slip resistance, there is even less on how to predict the more important property of slip resistance retention.

A polished surface may scratch and become rougher. A rough surface may slowly polish and become smoother until an equilibrium surface is achieved where the degree of polishing and scratching are equal for a given location.

It is this equilibrium surface that is the true measure of the performance of the surface. But it eludes prediction.

An idea of the potential performance can be obtained by slip testing a given stone material in the polished state and then variously rougher honed surfaces. If the values vary little then performance should be reasonably predictable, while a large variation indicates a stone that could require considerable maintenance to ensure a degree of safety.

Once an equilibrium surface for a stone is achieved, the next important factor is the rate at which it wears. Granites and quartzites will show good resistance because of their hard, siliceous minerals. Sandstones comprise siliceous minerals but may show low abrasion resistance because of their granular structure, allowing grains to be literally knocked out of their cementing matrix.

Marbles and limestones comprise softer carbonate minerals and will show less satisfactory abrasion resistance.

Determining the abrasion resistance presents the same problems as determining slip resistance in that there is no generally accepted test. The method most commonly employed is ASTM C241, Standard Test Method for the Abrasion Resistance of Dimension Stone.

This test is laboratory based, relatively simple and appears to have good repeatability. Samples of stone are placed on a lap revolving at a set rate with a set bearing weight on the specimen. A standard grit abrasive is applied continuously to the lap, which is run for a set period. The amount of material lost, the density of the stone and the bearing weight are used to calculate the abrasion resistance.

Comparing the TRRL slip resistance with the ASTM abrasion resistance provides data that appears to reflect true life performance. Some of these comparisons are given in Table 1, which also includes some basic physical test data.

Table 1. Comparison of basic characteristics of some stone types with slip and abrasion resistance

Stone Type	Finish	Density, kg/m^3	Absorption, %	Strength, MPa	Abrasion Resistance	Slip Resistance†	
						Wet	Dry
Quartz Sandstone	Sawn	2480	2.3	90-155#	23	79	79
Quartz Sandstone	Sawn	2270	2.8	105-130#	14	85	86
Sandstone	Honed	2355	3.5	10-20*	19	73	72
Caithness (Siltstone)	Riven	2665	0.2	105-125#	12	60	–
Siltstone	Riven	–	1.1	–	5	37	–
Slate	Riven	2740	0.4	44-65*	12	55	54
Slate	Riven	2745	0.3	46-82*	18	62	60
Serpentinite	Honed	2700	0.1	210#	42	30	57
Porphyry (Igneous)	Sawn	2550	0.7	230-275#	57	59	68
Granite	Picked	2605	0.5	115-180	44	69	67
Granite	Picked	2620	0.3	200-235	59	70	32
Dolomitic limestone	Honed	2700	1.2	100#	18	63	72
Hard limestone	Honed	2675	1.3	145#	17	63	60
Hard limestone	Honed	2660	0.6	115-165#	19	67	65
Hard limestone	Honed	2620	1.1	125#	37	35	54
Limestone	Honed	2405	3.5	7-12*	7	50	60

Abrasion resistance – the higher the value, the greater the resistance
* Modulus of rupture (flexural strength)   Slip resistance – the higher the value, the greater the resistance
\# Compressive strength
† The slip resistance values were determined using the TRRL test with a 4S (which stands for 'standard simulated shoe sole') rubber for which the UK Slip Resistance Group have provided the following classification for slip resistance values (SRV): SRV >65 = excellent; 35-64 = satisfactory; 25-34 = marginal; <24 = dangerous.

Table 2. Typical slip performance of major stone types

Stone Type	Polished	Textured
Granite	Good resistance in dry conditions, low to moderate resistance in the wet	Good resistance in wet and dry conditions but may polish with wear to reduce wet resistance
Black Granite	Good resistance in dry conditions, low to moderate resistance in the wet	Good resistance in wet and dry conditions but may polish with wear to reduce wet resistance but to less degree than granite
Marble	Good resistance in dry conditions, low to moderate resistance in the wet	Good resistance in dry conditions but may polish rapidly with wear to reduce wet resistance
Travertine	Can maintain excellent resistance if the holes remain unfilled, otherwise similar to marble.	Not normally textured, rather holes remain unfilled to offer excellent slip resistance in both wet and dry conditions that is maintained with wear
'Hard' Limestone	Highly variable depending upon the porosity, resistance in the wet increasing with increasing porosity normally at the expense of abrasion resistance	Good resistance in dry conditions but may polish rapidly with wear to reduce wet resistance
Limestone	Difficult to polish but good resistance wet and dry	Good resistance in wet and dry conditions which should be maintained with wear, that may be rapid
Sandstone	Excellent resistance wet or dry, rarely able to be highly polished	Excellent resistance in wet or dry conditions that is maintained
Quartzite	Low resistance in the wet, excellent in dry	Excellent resistance in wet and dry conditions that is maintained although surface will eventually begin to polish
Slate	Difficult to maintain polish, good resistance in dry conditions, moderate in wet.	Excellent to good resistance in wet and dry conditions that is maintained, will become smoother with wear

Ideally, the way slip resistance of stone is measured should be standardised at a specific grade of honing and in the most highly polished state.

But back to the question of whether there is a perfect flooring stone. There is only one answer: if you maintain a correctly installed surface, all stones can provide adequate performance but none is perfect for all possible situations.

Table 2 provides a summary of typical performance for the major stone types. This table is for general guidance purposes only and any specific stone proposed for use in flooring should be assessed individually.

Having selected

neighbouring country, making such legislation apparently irrelevant. Nevertheless, each small piece of action goes some way to making the global total of emissions less than it would otherwise have been and over the past decade total emissions from the UK have begun to fall.

There is still no universally accepted method of dealing with stone decay resulting from air pollution. Every stone in every situation must be individually assessed.

Surface treatments can be exceptionally expensive and the success of a treatment on one kind of stone does not assure its efficacy with another.

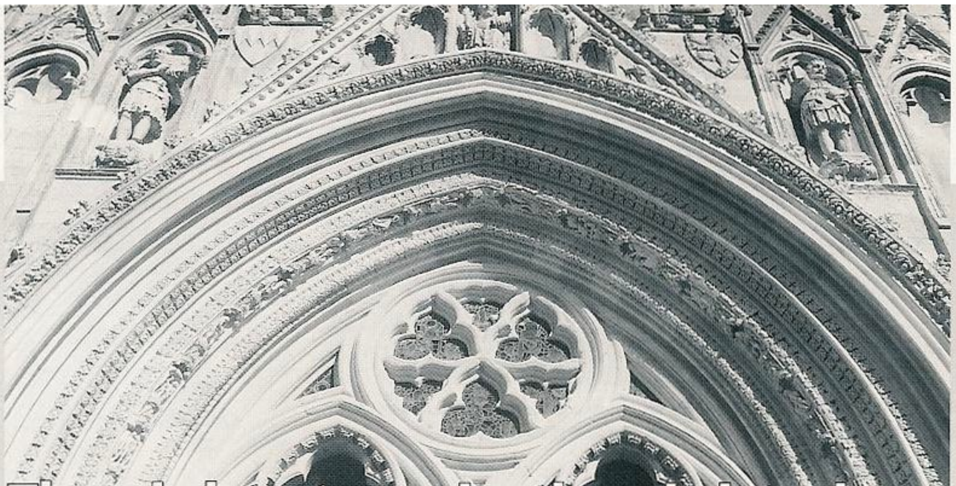
Further, treatments which prevent or restrict the ingress of pollutants in liquid or gas forms may also create a detrimental barrier to the escape of moisture, salts and other media from within the stone. In some instances a treatment may accelerate decay, in the worst scenario even leading to the premature loss of the whole surface.

Unless there is a dramatic change in environmental policy across the globe, we have to accept that all materials are liable to decay in service partly in response to pollution. Stone is no exception.

But if we cannot be sure that our efforts will benefit the stone, is conservation worth the risk? Or do we accept restoration – the replacement of damaged stone, like for like – as being the only viable alternative? There are no easy answers.

The pollution problem does not appear to be a great issue with modern building planners as most have short design lives and expect to be re-fitted, sometimes even within a decade. Furthermore, some prestigious modern cladding systems employ granites and similar hard, low porosity stones that are best able to resist pollution.

Stone in new-build is, though, being used in more ➩



The right stone in the right place

By Ged Smith of Ibstock Building Products

One of the delights of travelling the more rural byways of the UK is noting the local, or vernacular, architecture and relating it to the countryside where it is found. Building materials were heavy and bulky so, unless they were irreplaceable or the developer was wealthy, our forebears did not transport them long distances.

Thus the architecture of London, the Midlands plains and East Anglia are historically brick from local clay deposits (apart from the mansions of wealthy landowners and prestigious buildings in areas such as the City of London).

Where stone was readily available, it was used. And in such a geologically diverse island as ours, a rich variety of stone, too. The honey-coloured Cotswold limestones immediately spring to mind, the gritty sandstones of Yorkshire, the pink granites of Aberdeen and the various-coloured slates of Wales show what lies under the green turf.

An unfortunate by-product of our industrial heritage and damp climate is that much of our stone has been eroded by high levels of pollution for 150 years or more. This is not just a problem associated with the internal combustion engine. Coking gasworks were introduced in the late 19th century and could be every bit as damaging to buildings down wind.

The ill-advised juxtaposition of several different materials on a building, such as limestone cills on a sandstone wall – favoured particularly by the Victorians – accelerated these problems as rainwash from the limestones reacts with the sandstone.

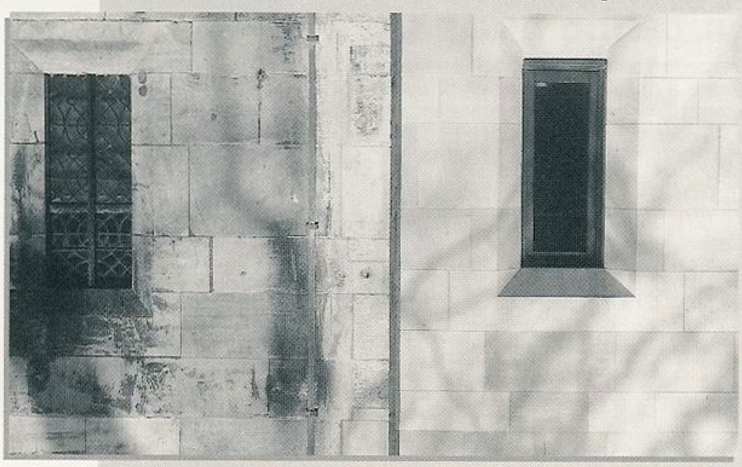
When replacing or refurbishing stone, especially on buildings of national importance, it is important that the new stone weathers to the same appearance as the old. To achieve that, it is necessary to use natural stone as close to the original as possible. A recent example is the refurbishment and extension to the library at York Minster.

This is one of the most important medieval buildings in England, and the work on it was carried out using smooth grained Cadeby magnesian limestone from South Yorkshire. The 500m² extension is finished in dressed ashlar and all additional components, including plinth, string courses, cills and copings, are also in Cadeby.

The masonry and carving work for the extension and refurbishment of the original building was carried out by Cadeby suppliers Ibstock (who also sell bricks and reconstituted stone). Fixing was the work of William Birch & Sons, the main contractors on the project.

The new extension butts onto the 13th century former chapel of the Archbishops of York, itself built of magnesian limestone, which has served as the Minster library since the early 19th Century.

The extended building occupies a prominent position in the Minster and the importance of the quality of its appearance cannot be underestimated. By using local limestone, the extension will soon blend with the adjoining 700-year-old building.



Above. The original, 700-year-old building of York Minster and the new extension. The difference is stark now, but the new Cadeby limestone will quickly weather to match the older stonework.

Top. As well as the extension, the original building of York Minster was refurbished, the stone being replaced where necessary with Cadeby magnesian limestone from Ibstock Building Products.