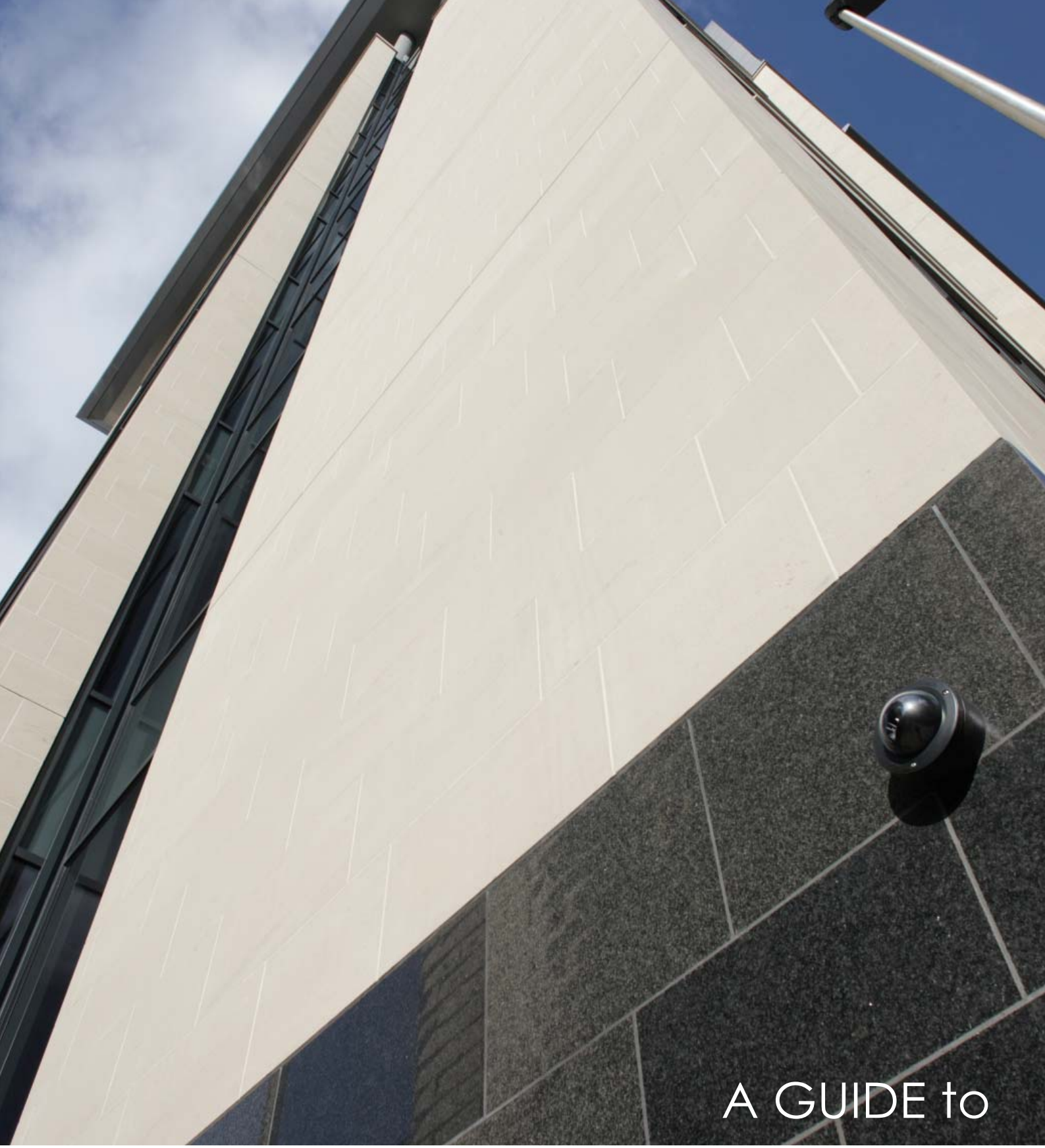
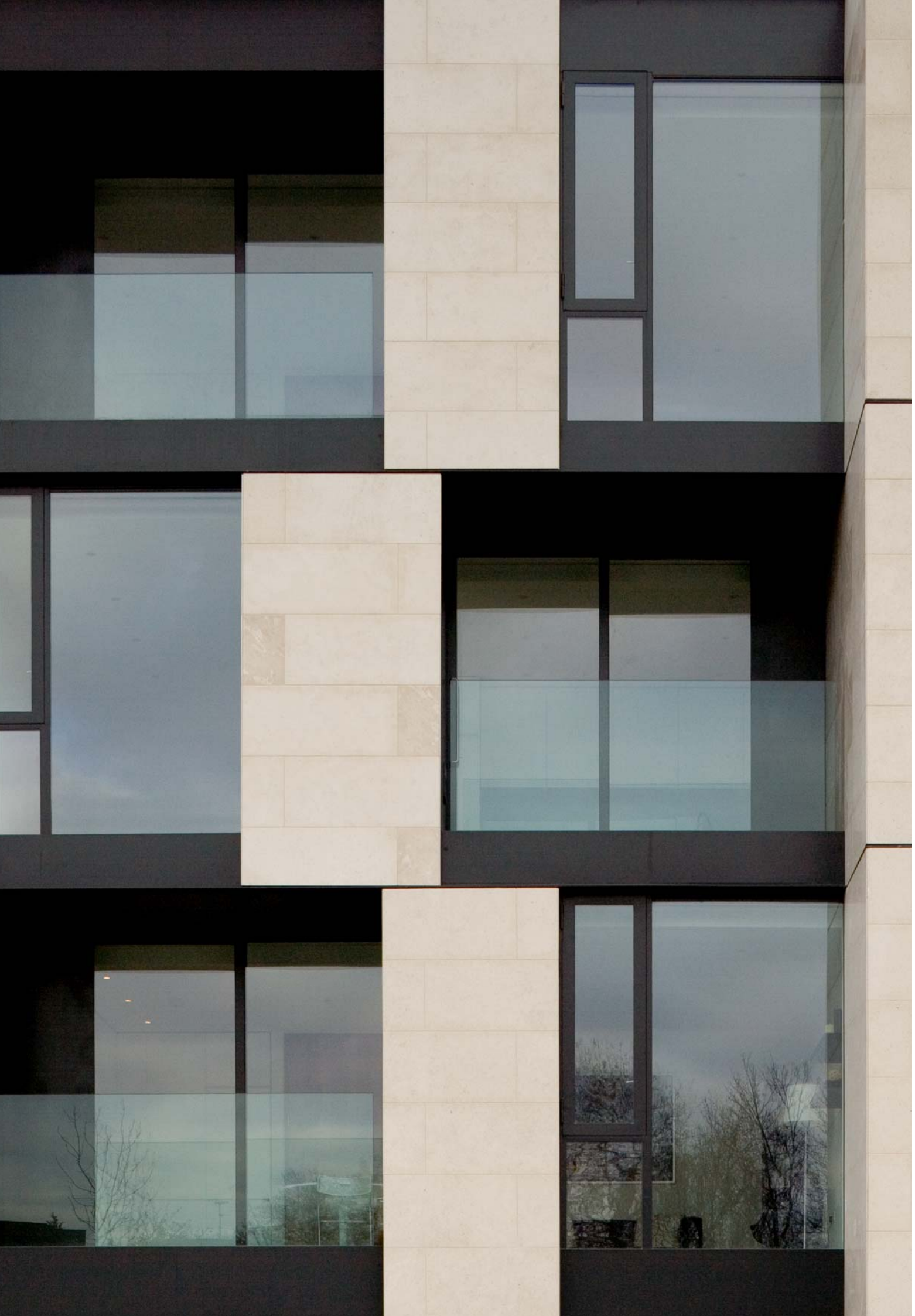


A GUIDE to

BS 8298

Federation Stone
Great Britain



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A Guide to BS 8298

Introduction

These notes deal with the changes to the British Standard Code of practice series BS 8298; the design and installation of natural stone cladding and lining; Parts 1, 2, 3 & 4. They should be read in conjunction with and as a supplement to these new Codes, and are not seen as an alternative document to the Code.

Note: wherever specific criteria or values are defined in this document, they should always be verified by reference to the current version of BS 8298, to ensure they have not been superseded through subsequent amendment.

Main points that have changed;

- Recording of the geological name and CE Marking of all stones
- Greater detail about initial testing and sampling plans, as well as the differing statistical presentation of results
- Entirely new section (part 4) on Rainscreen Cladding metal framed systems
- Factors of Safety, criteria that need to be considered
- Thickness calculation for cladding
- Greater information on the risk of impact.

The aim is that these notes will give the reader a better understanding behind the reasons for the changes from the original earlier BS 8298 (1994) document and provide some useful suggestions for the correct use of stone as a cladding material. We have tried to pull similar aspects of the Code together to ensure that related items are read together in these notes. The cross-references to the sections of the BS 8298 do not run in numerical order. We have used the following headings to assist the reader to find the relevant section;

1. **Geology/Samples**
2. **Testing**
3. **Design of the cladding**
4. **Factor of safety**
5. **Thickness calculation**
6. **Impact resistance**



Stone Consultants

Stone Federation recommends that you employ the services of a Stone Consultant to assist the team with queries about the stone selection process. It is important that the Stone Consultant has the correct level of geological experience and expertise to be able to properly advise and it is equally important to involve the consultant in the entire selection process, most particularly the quarry visit and the selection of the samples to be tested.

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1. Geology/Samples

Geological Name and CE Certificate

This is the first time that the geological names of the stone and the requirements for a testing regime, including the actual testing samples for the different varieties of stone to be tendered, have been included in the Code, see Part 1 Section 4.3.1 (e) & (m).

The geological name of the stone must be provided, together with a petrographic description – these should be in accordance with the definitions in BS EN 12440. From July 2013 all stones will have to be supported by a CE Certificate relevant to its purposed use. This certificate, produced by the company that first places the stone product on the market in Britain or into other CEN member states, shall show the technical properties of the stone.



Why are the correct stone identification and the CE certificate so important?

- To access all the stone's historical technical information, compare this to new data and to assess reference building using stone.
- To be able to visit the quarry to assess stone variation and establish an acceptable range, and prepare a sampling plan if additional samples need to be tested.
- As the new Code contains no prescription for panel sizes or stone thickness the designer must ensure that the stone selected is supported with the relevant test data so that the appropriate calculation can be completed.
- To bring transparency at tender stage of the stone's correct name, providing an even playing field for tendering sub-contractors and providing the client with certainty of the material to be provided.

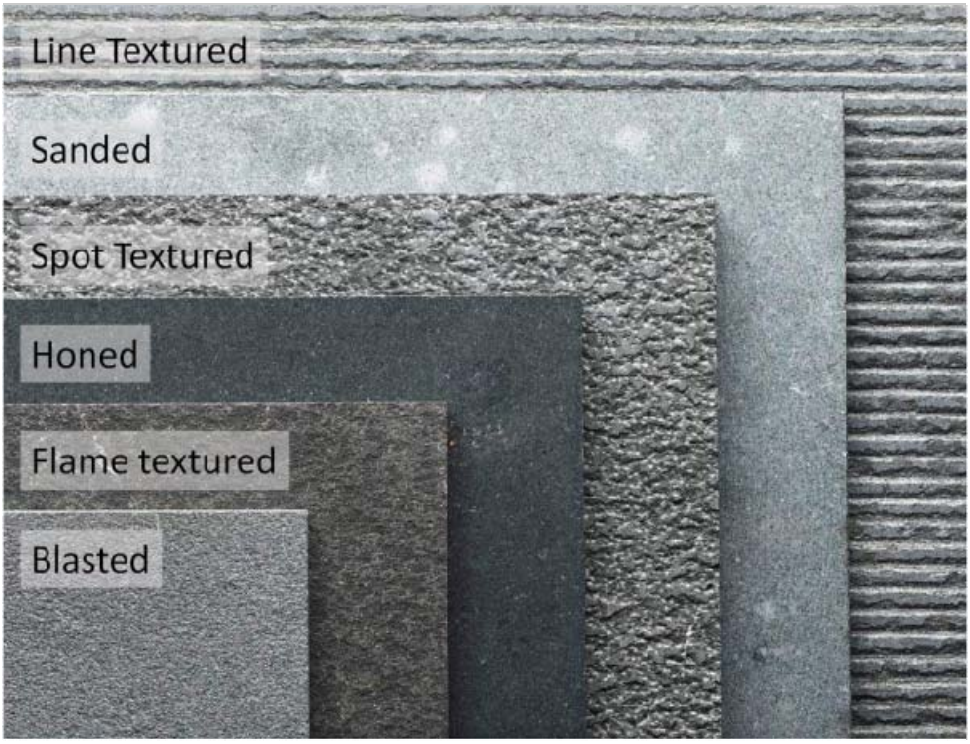
Face bedded stones

Part 1 Section 5.1.3 explains that the orientation of the bedding could affect the technical properties of the stone; some stones are structurally weaker in certain orientations. It is therefore, important to understand the bedding orientation of the stones that have been tested. Most indigenous stones are naturally bedded (the bedding running horizontal, or nearly so, as viewed) whereas many imported stones are routinely produced face bedded (the bedding in the same plane as the cladding panel). It would be wise to seek the opinion of a geologist/stone cladding specialist with geological knowledge if there is uncertainty about the data or its potential performance.

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Stone Finishes

The stone finishes are set out in Part 1 Section 5.1.6, and describe the spun finishes and the grit sizes used; rough ground F60, medium ground F120, fine ground F220, matt finished F400 and highly polished using a polishing disc or felt. The grit sizes are very important, as just relying on the description is likely to result in confusion as historically, finishes are often quoted in local terms. The grit size should always be quoted on indicative samples, control sample/range panels and in all specifications, as different stones may require different grit sizes to produce a similar finish. Please be aware that some surface finishes, such flame texture can affect the flexural strength and increase the water absorption of the stone.



Indicative and Control samples

The difference between the Indicative, small samples that just show an indication of the 'typical' colour and texture, and Control (or Range) Samples, that are a number of large panels that show the range of typical geological features that are likely to be present in a façade is explained in Part 1 Section 6.12, 6.12.1 & 6.12.2. Representative control samples should be agreed for every project, but the team need to be aware that a tight selection in the control samples of typical geological features will potentially increase wastage and, therefore, the associated impacts on the environment from the extraction process.

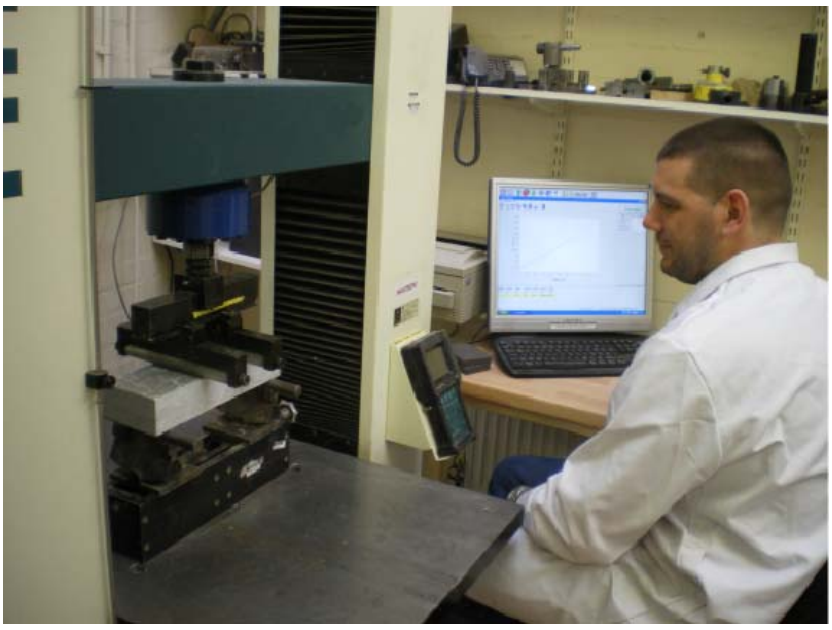


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2. Testing

Existing Technical Data

There are various independent publications that will give you some preliminary technical information on stone. These include the BRE limestone and sandstone books (please note that these were written in the late 1980s and some of the grading of the durability results have been superseded by new Standards), BRE stone list (compiled in 2002) on the web site *http://projects.bre.co.uk/condiv/stonelist/ stonelist.html*, the Natural Stone Directory and the Geological Society EGSP No 16 ('Stone: Building stone, rock fill and armour stone in construction', published in 1999 and including an appendix on stone and rock properties). Many extraction companies will provide technical data about their stone and some are currently providing it in the CE certificate format, but all companies will have to comply by July 2013.



CE Certificates

The CE certificate will ensure that the data is consistently obtained and presented in a format common throughout Europe, which will allow for an accurate comparison between differing stones. The stones will have the mean and a statistically Lowest Expected Value (LEV) calculated based on a 75% confidence level**.** Care must be taken if data is not tested in accordance with EN testing methods or is not supported with a CE Certificate. A single mean figure could be very misleading.

Similarly a simple unexplained range of the results can also be misleading as it could be a range of actual results, average results or lowest/highest expected values.

It is important to be able to check the dates that the tests were conducted. Ideally the tests will have been repetitively performed over a long period of time, including some recent results. Stone Federation therefore recommends that the CE certificates should be prepared using all the available results; current as well as historical, so that the LEV and mean figures are truly representative of the stone.

Unless there have been significant changes in the geological character of the stone in recent production (this can be assessed by looking at past projects), older tests may still be valid as indicating current technical properties.

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Initial Testing

After collating the available existing technical data it may be necessary to conduct some preliminary testing to confirm the suitability of a stone on the shortlist; a stone consultant will be able to help interpret the data. It is important that these tests are completed in plenty of time to react to any unexpected results that may involve elements of a redesign on the stone thickness for example, or even the replacement of the stone on the project.

If no historical or reliable historical data is available then Stone Federation recommends that the initial testing should cover a wider range of samples than the minimum required. We would suggest that at least five blocks from different locations on the production face/stock are used to cut enough samples for five sets of testing

All tests should be to British/European Standards (not ASTM, the North American Codes) and tests should be completed at an independent UKAS-accredited testing laboratory.

Table 1 in Part 1 sets out the test methods. Depending on the tests selected, please be aware that some tests can take up to 10 weeks to complete and additional time will need to be set aside to complete the sampling plan and for the physical cutting of the stone samples for testing. Additional testing should only be at the instruction of the stone consultant or to confirm the stone properties for a unique application or fixing system.



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Relevant Tests and Wet Flexural Strength Testing
Where additional testing is required these tests should be related to the actual project requirements rather than just a list of all the available tests. A stone consultant will be able to assist you with the selection of a testing regime specifically designed for your project.

Although wet strength testing does not form part of the European Standards, the UK stone industry feels there is a benefit in conducting, in addition to the standard dry tests, a simple variation to these flexural strength tests to assess strength reduction when the stones are saturated. The method is set out in Part 2 - Section 4.3.2. Section 6.1.4 in Part 4 gives more information on the factor of safety calculation; also see section 4 in these notes.



History of Use
Part 1 - Section 5.1.9 and Table 3 shows the importance of reference projects. Stones that have a good history of use on similar projects and locations, as the project will obviously require significantly less evaluation than a new stone to the project's location. It is important however to verify that the historic stones used for comparison are from the same source and that there have been no significant changes in geology and structure at the quarry source.

Good history of use can be assessed by looking at a number of factors, but mainly the durability of the stone itself and any reduction in the strength as a result of weathering. A number of buildings need to be reviewed, ideally at least five, and the services of an experienced Stone Consultant may be required. Whilst the durability is relatively easy to assess, by simply looking at exposed stonework and comparing it with the stone in more sheltered situations, a reduction in strength is more difficult to assess. The factor of safety Section 4 gives more information on this topic.

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The testing should also reflect whether some of the data are near to the unsatisfactory or marginal requirement for the project or if the stone is being used in an application that puts additional stress on the stone. A marginal result should be clarified as a result within 10% of the required level.

It is likely that different stones on the project short list will require different levels of testing that will impact on the cost of these stones and possibly the programme.



Production Testing

Factory Production Control (FPC) testing can (or may) be carried out to confirm the ongoing consistent quality of the stone as it is produced, if required. The initial testing should have already confirmed that the stone is suitable for the project. The frequency of the Production Control testing will be affected by the typical changes in geology of the stone, whether the stones are available (all or partly) from stock and the extraction progress/number of differing extraction areas in the quarry or mine.

It is important to remember that the samples for production testing are taken as the stones are processed, so by the time the results are known the stones from the block will have been produced and in some instances, fixed onto the building.

An appropriate factor of safety for stone will allow for the typical variations of the natural product; however, the production testing may indicate a trend in the physical properties of a stone that needs further investigation.

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Testing Sample Plan and Report

It is important that any sample submitted for testing is representative of the typical properties of the stone. A sample plan should be prepared in compliance with the requirement set out in Annex A of Part 1 and in the relevant Euro-code, such as BS EN 1469 Natural Stone Products – Slabs for Cladding - Requirements.

EXAMPLE OF **SAMPLING PLAN**

Sampling Plan

Sampling plan no:	Sample Plan Number 001

Project Details

Project name:	Oxford Street
Project ref no:	W0001
Company for whom sampling plan undertaken:	The Big Building Company
Company sampling plan prepared by:	Albion Stone Plc

Stone Details

Name of quarry or factory:	Jordans Quarry
Name of stone:	Jordans Basebed
Location of sampling points:	(See enclosed plan for locations of 3 sampling points)

Tests for which samples to be used

Test: BS EN 1925: 1999 – Water Absorption		
Quantity 6 samples	Sample size 50mm x 50mm x 50mm	Bed orientation Marked with parallel lines
Test: BS EN 1926: 1999 – Comprehensive Strength		
Quantity 6 samples	Sample size 50mm x 50mm x 50mm	Bed orientation Marked with parallel lines
Test: BS EN 12407: 2000 - Petrographic		
Quantity 1 sample	Sample size 150mm x 150mm x 50mm	Bed orientation Perpendicular to bedding
Test: BS EN 13161: 2001 – Flexural Strength under constant movement		
Quantity 10 samples	Sample size 300mm x 150mm x 50mm	Bed orientation Perpendicular to bedding
Test: BSEN 1936: 1999 – Density and Porosity		
Quantity 6 samples	Sample size 50mm x 50mm x 50mm	Bed orientation Marked with parallel lines

Samples

Method of obtaining samples: Middle slabs cut from selected blocks
Apparatus to be used for sampling: Samples to be cut at factory on secondary saws
Comments:
This sampling plan was prepared by David Williams Please contact David Williams, tel no: 01305 860369 if further information is required.

The sampling plan should define the extraction, cutting and working of the samples for testing. It should show the approximate proposed or actual locations in the quarry or mine that the block will be/have been extracted from on a plan, as well as the number of samples for the various tests. The sampling plan will either be prepared by the quarry/mine or a stone consultant for approval by the client/design team. As the samples are cut, a sampling report should be completed. This provides traceability of the physical samples through to the testing laboratory.

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3. Design of Cladding

Manufacture tolerances Part 1 - 7.0
The tolerances as stated in BS 8298 are the normal production tolerances and are suitable for the industry norm of 5mm joints +/- 2mm. Tighter manufacturing tolerances can be specified if narrower joints are desired, but the potential rejection rate together with cost implications, the associated unwanted wastage in relation to the overall utilisation of the natural material and the cost implication of the checking of the tolerances properly (i.e. not with a tape but electronic callipers) needs to be considered, particularly if a manufacturing tolerance of +/- 1mm is required.

Mortices Part 1 - 7.3
Where the stone thicknesses have been calculated using the breaking load at dowel hole, the accuracy of the drilling for the dowel hole and all other associated fixing sinkings or nibs is vital. Where this has been completed as a site operation, this may not provide the level of accuracy required for thinner cladding.

Soffit Part 2 - 4.6
Soffit stone will also be covered by the new thickness calculations; see Thickness section below. It is recommended an experienced cladding designer is employed to assist with the design and the thickness calculations.

Glued and Pinned returns Part 2 - 5.14
Glued and pinned returns have been used as a cost effective alternative to a solid stone or notched stone. It is important that these operations are completed to a high standard so all glued and pinned returns are to be fabricated in controlled conditions at works. The length of the return needs to be carefully considered and the joint detail can be either butted or bird's mouth (latter normally only used for marbles and granites).

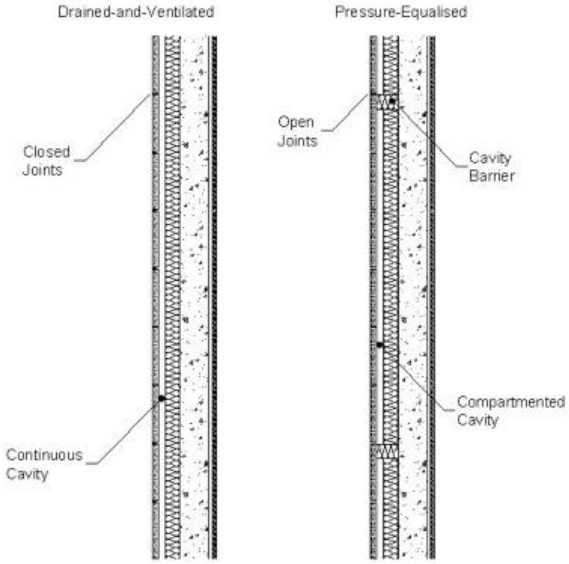
Permissible Deviations Part 2 - 8
There is often disagreement on site regarding erection tolerance. The tolerance of the erected cladding takes into account the manufacturing tolerances of the stone elements as set out in BS 8298-1 and the tolerance permitted for the structure as set out in
BS 5606. Table 12 sets out suggested tolerances that deal with this matter. If tighter tolerances are required these must be set out in the specification. Achieving tighter tolerances will increase production costs and possibly the environmental costs of the stone and fixings and is likely to delay the programme.





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Rainscreen Part 4 - A rainscreen system is a panellised cladding system, in which some joints between the cladding panels are deliberately left open. The open joints permit some water to get past the cladding panels, but they also allow an air flow behind the panels which will dry the water out.



The joints can be shaped so as to minimise the amount of water which gets through, or a device may be employed partially to block or baffle the joint, but this is not an essential requirement. The open joints must not be so narrow as to be blocked by water or ice, either of which would compromise the performance of the system. Water management is essential to ensure that large, ever-increasing quantities of water cannot run down behind the rainscreen panels over a height of several storeys.



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Fire issues are important, and the designer must take care to ensure that fire cannot spread behind the rainscreen panels. Thermal performance is affected by the need to provide fixings which may pass through the primary insulation layer of the façade, and the designer must allow for localised heat losses due to fixings. These issues are exacerbated if stone panels are mounted on an intermediate metal framing system.

The designer must be familiar with rainscreen cladding systems, must have a track record of analysing and designing such systems, and must carry a suitable level of PI insurance.

Pressure-equalised/Drained and Ventilated. Part 4 - 5.2 & 5.3 A drained and ventilated rainscreen system is one where the cavity behind the panels is extensive and may span over several storeys in height and several bays in width.

A pressure-equalised rainscreen is one where cavity barriers are used to sub-divide the cavity into small elements, which are typically no greater than a storey high and a bay width, and may be even smaller near corners and eaves.

Most rainscreen systems are drained and ventilated – they are cheaper and simpler to install.

Pressure equalisation offers higher levels of performance. Providing the ratio of open joint area to cavity volume is sufficiently high, then the pressure in the cavity rises rapidly during gusts of wind, creating a back-pressure which limits the flow of water through joints.



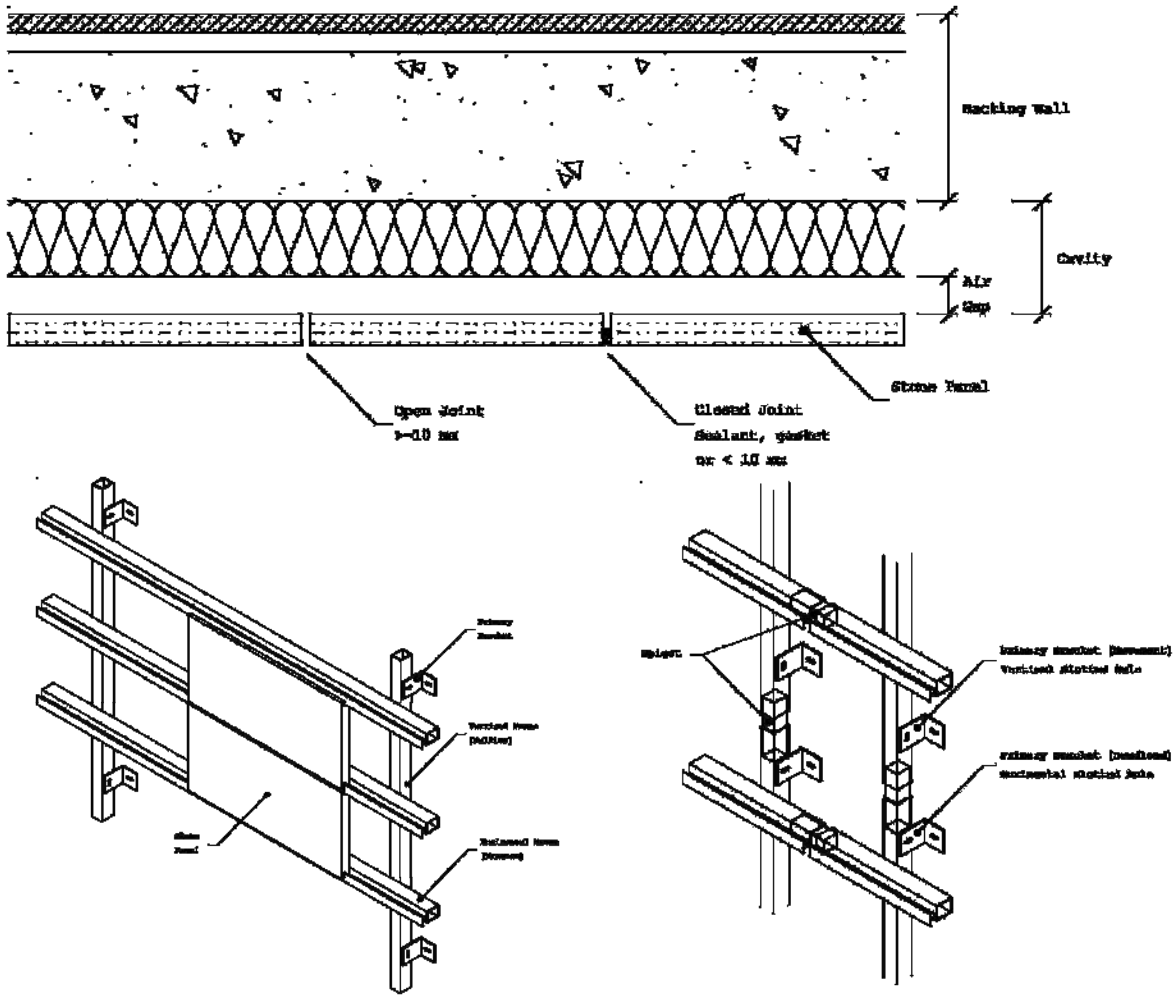


Rainscreen Framing system Part 4 - 5.4.3 Framing systems have continuous metal (typically aluminium alloy) frames which support the stone panels. Each stone panel is individually fixed to a pair of horizontal or vertical frame members.

The horizontal frame members are either fixed directly to the building structure or to an intermediate vertical framing member which is fixed to the building structure. The frame members are frequently fixed to each other or to the building structure at intervals which exceed the size of individual stone panels. This type of system does not require a continuous backing wall – the frames may be secured to the building structure at storey intervals.

The stone panels may be fixed to the frames using traditional direct fixings, traditional fixings to an intermediate bracket, or using proprietary clips which are specific to the framing system. The use of intermediate fixing brackets or proprietary clips often allows individual stone panels to be removed or replaced without dismantling the entire system.

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Rainscreen Movement Part 4 - 5.4.3.2 Intermediate framing systems must be designed to accommodate differential movement of the building structure and stone panels.

Movement can occur due to settling or drying out of the building structure, differential thermal or moisture expansion and contraction, swaying of the building under wind load or loading of the building structure in service.

Movement of the stone panels relative to the framing system can be accommodated by using slotted holes in fixings, or by allowing fixing brackets to slide on the framing system (one bracket is typically locked in place to prevent 'walking' of individual panels).

Movement of the framing system relative to the building structure can be accommodated by using slotted connections at fixing points (one locked or non-slotted fixing point must exist, to support the weight of the system).

Movement of one part of the framing system relative to another can be accommodated by using spigots in joints between consecutive lengths of framing.

Care must be taken to avoid mounting stone panels across a movement joint, unless the panel is fixed on one side of the joint only.

The designer must be careful to ascertain what degree of movement is expected.

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Rainscreen Pressure Equalisation Part 4 - 5.5.2 When air rushes through a joint into a cavity it causes local pressurisation of the air in the cavity.

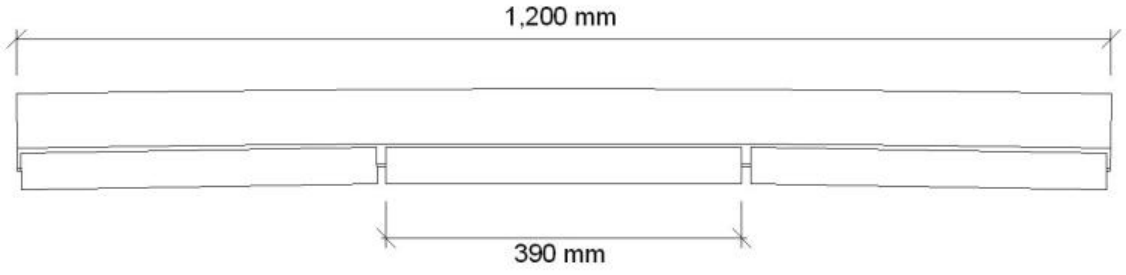
If the enclosed volume of the cavity (referred to as a 'compartment') is sufficiently small in relation to the joint size then the pressure of the air in the compartment may reach a significant proportion of the pressure on the face of the rainscreen panel. This reduces the net pressure difference on both the panel and across the joints. The reduced pressure difference on the panel may allow thinner stone to be used. The reduced pressure difference across the joints reduces the amount of water which blows through the joints.

For the drained and ventilated case, assume that the cavity is 10 storeys in height and a structural bay in width. There is a pair of open joints per cavity, one at the top and one at the bottom. The open joints are 10 mm wide and have a net length of 12,000 mm. The depth of the cavity is 150 mm (including the insulation layer, which for the sake of this example is taken to be mineral wool, which contains a significant volume of air and so contributes to the volume of air in the cavity), and the width and height of the cavity are 6,000 mm and 32,000 mm respectively. The volume of the cavity is 28.8 m^3 (0.15 × 6.0 × 32.0), and the net area of open joint is 0.12 m^2. The ratio of volume to joint area is 28.8/0.12, or 240.0. This is greater than 80 and so this cavity is not pressure equalised. This is a typical drained-and-ventilated cavity.

For the pressure-equalised case, assume that the cavity/compartment is one storey in height and a structural bay in width. There are six open joints in the height of the cavity. The open joints are 10 mm wide and have a net length of 36,000 mm. The depth of the cavity is 50 mm (excluding the insulation layer, which for the sake of this example, is taken to be a closed cell foam plastic insulation, which can be regarded as solid and does not contribute to the volume of air in the cavity), and the width and height of the cavity are 6,000 mm and 3,200 mm respectively. The volume of the cavity is 0.96 m^3 (0.05 × 6.0 × 3.2), and the net area of open joint is 0.36 m^2. The ratio of volume to joint area is 0.96/0.36, or 2.7. This is less than 80 and so this cavity can be regarded as being pressure equalised.

The horizontal cavity barriers may also act as fire and smoke stops.

Rainscreen Deflection Limits Part 4 - 6.1.5 Consider the example shown in the figure. Overall the horizontal framing member spans 1,200 mm between fixings. The allowable mid-span deflection of the framing member is L/360 or 3 mm. L/360 gives a deflection of 3.33 mm, therefore the allowable limit is 3 mm, and the frame member should be sized accordingly.



The individual stone panel is 390 mm wide. The allowable deflection of the framing member over this length is L/360 or 3 mm. This gives a minimum deflection of 390/360, or 1.08 mm. The designer must also check that the selected framing member achieves this requirement.

It is essential that adjacent framing members have parallel fixing points so as to avoid twisting the stone panels.

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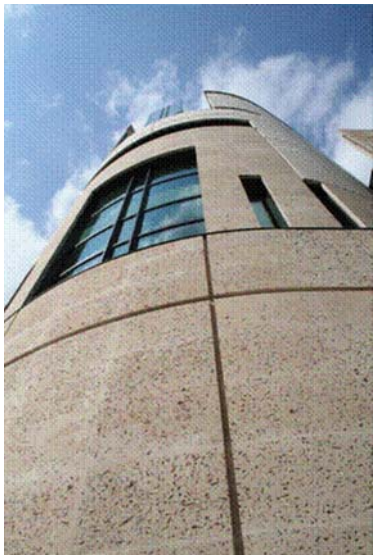
4. Factor of Safety

There has long been a sense that stone cladding systems are over designed, particularly in the UK, where typical cladding thicknesses have been 75 mm for limestone against perhaps 40 mm in Continental Europe. This discrepancy has been challenged in recent times with thickness more frequently being determined by engineering calculation, as in the new version of BS 8298, rather than the Standard table given in the old version.

The calculation introduced in the new version method requires two very important pieces of information with regard to the stone. The first is the bending strength of the material. This is usually taken as the mean flexural strength of the stone and in accordance with current European Standards, this would be the strength when tested dry.

The second piece of information that would be required is 'what is the appropriate factor of safety to be applied?' This has commonly been taken to be six when applied to the mean flexural strength result.

This is not a worldwide view and there are many countries (the USA for example) where the factor of safety differs according to the stone type. This approach seeks to attribute higher factors of safety to classes of stones which are thought to be more variable in their properties.





The factor of safety is supposed to take into account all aspects of the material variability; however, with some stone types this is unlikely to be the case. For example for white marbles the strength loss over time can be considerable.

How should the designer seeking to use the BS approach the problem of factors of safety? The work previously carried out by the Centre for Window and Cladding Technology (Guide to the Selection & Testing of Stone Panels for External Use – published in 1997) has, to some extent, described a possible way forward.

This captures the differences in stone performance by using the actual variability of test results on individual stones. Of course such an approach pre-supposes that recent test data is available for the stone or that (sufficient) project specific testing will be carried out. Given the move to CE Marking and product verification, we believe that this is a reasonable approach.

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There are two options, over and above the requirements in BS 8298, that can be considered by the designer in conjunction with the evaluation of specific project parameters.

These are;

Option 1

Where a stone is well known and has a proven in-service durability record, there should be sufficient existing data available to the project team to allow them to compare current production to historical results. Assuming that the stone type is well known and durability issues can be ignored on the basis of a demonstrable knowledge of the in-service performance of the material in a similar environment to that in which it is to be used, then the wet or dry values can be used in any calculation. Stone Federation defines 'well known' as at least 20 buildings in the same or similar environments over 50 to 100 years without significant durability issues.

However, rather than use the mean strength value, British Standards allow for the calculation of the 'lowest expected value' (LEV) which takes into account the statistical variation in the individual strength values obtained in the test. Under such circumstances, having taken a somewhat cautious approach with the testing by using the LEV rather than the mean, the factor of safety (FSF) which is typically adopted, is three rather than six. This can be adopted for all stone types as the material variability has been allowed for in the LEV calculation.



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Option 2

Where the durability characteristics are not well known then a different approach is required. The objective is to determine a durability factor rather than rely on subjective factors of safety. So, in addition to dry and wet testing, a number of flexural strength samples need to be subjected to a durability test, the precise nature of which will be dependent on the stone type.

The durability test selected will be dependent on the stone type and the anticipated exposure conditions. For marbles this will be a thermal cycling test. For some limestones or sandstones it may be a frost test (depending on geographic location of the project) or a combination of thermal cycling and wetting and drying. Once the samples have been subjected to the durability test they should then be tested for flexural strength and the lowest expected value obtained. These values are then compared with the values obtained before durability testing and a comparison made.

The durability factor will be as Table 1

Fraction of Initial Flexural strength % after appropriate durability testing	Durability Factor
95% to 100%	1
75% to 95%	1.2
60 to 75%	1.5
50 to 60%	1.8

If igneous or metamorphic stones show a reduction beyond 75% and the sedimentary stones below 50%, then the mechanism of that reduction in durability needs investigating by a stone consultant with a strong geological background. Obviously, if any samples show indications of cracking, spalling or deformation after durability testing, then they should not be considered further. If they simply show a strength loss then the durability factor can be adopted. The calculation remains the same but the flexural safety factor is multiplied by the appropriate durability factor described above.

This works as follows:
For a stone which lost, say 20% of its strength in the frost test, the calculation of the factor of safety would be 3 multiplied by the durability factor, which in this case is 1.2, giving an overall factor of safety of 3.6.

The LEV value used would be that obtained on the flexural strength tests in the wet condition after the frost cycling.

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5. Thickness Calculation

The panel thickness should be determined at an early stage of design (stage C or D), so as to influence key decisions relating to the façade setting out and wall construction make up.

There are two modes of failure for the stone panel that relate to the stone thickness;

- breaking due to the lateral load
- breaking at the fixing point.



Ideally the thickness of stone cladding needs to be determined by **calculation** as per the methods stated in Section 4 Part 2, but it can also be assessed by using the tables in the new **Annex A** in Part 2. These tables give the recommended thickness based on satisfactory past experience, so will tend to result in thicker stones, which may be suitable for smaller projects, but may result in unnecessary stone (cost and weight) for larger projects.

- Stone Thickness Determined by Calculation

Assuming the calculation to assess the most appropriate thickness is completed, there are various factors that need to be considered and information that is required:

1) the lateral load on the building
2) the fixing system
3) the panel size
4) the stone's technical properties:
   a) the flexural strength
   b) the breaking load at dowel hole
5) the factor of safety to be used.

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1) The lateral load on the building

This wind load can be calculated using the methods and factors given in BS 6399, which will provide an accurate figure for the lateral load on the stone panels. If for whatever reason the project specific lateral load calculation cannot be completed then the Table 1 in Part 2 of BS 8298 can be used instead. This pressure in N/m^{-2} (q) is used in the calculation for the thickness of the cladding. Table 2

CLASS	*LOAD*	*BRIEF DESCRIPTION*
Low wind load environment	*1500 N·m⁻²*	*Sheltered environment such as the lower floors of a building in a central urban area, e.g. Central Manchester*
Medium wind load environment	*2250 N·m⁻²*	*A more exposed environment such as the higher floors of a tall building or a more exposed location, e.g. Canary Wharf, London*
High wind load environment	*3000 N·m⁻²*	*An exposed environment such as a coastal location*

2) The Fixing System

The support of the stone will impact on the thickness calculation. Normally it is assumed that it will be four 6 mm dowels in the longer lengths, the top and the bottom edges of the stone panel. From the location of the fixings the greatest panel span, the maximum distance between the fixings measured parallel to the side of the panel, can be measured/calculated. The number of fixings forms part of the strength at fixing point calculation.

3) Panel Size

The panel size will affect the calculation as the bigger the panel the greater the lateral load and more force is applied to the stone and the fixings. The panel sizes in mm are used in the thickness calculation; b is the width and L the span.

4) Stone Technical Properties

It is vital that the stone selected has adequate and current technical data results; tested to the correct Euro-code testing standard with a CE certificate, also see Section 1 and 2 of these notes. These data sheets/certificates will provide the figures for the flexural strength and the breakable load at dowel hole (which is dependent on the thickness), either as a mean figure or a lowest expected value (LEV). Stones that have a large number of test results over a long period will provide the most reliable mean and LEV figures. Most porous stone will suffer some strength reduction when tested wet, so the wet test results will provide the most conservative strength values. The stone flexural strength (Dfb) will be used for the thickness calculation and the dowel pull out figures for the strength at fixing calculation.

5) Factor of Safety

See section 4 of the notes, but it is important to understand the impact of mean or LEV and dry or wet results and the previous proven service record of the proposed stone on the appropriate factor of safety to be used. This flexural safety factor (FSF) is used as part of the calculation for the thickness.

To calculate the correct thickness of the stone, the following properties need to be assessed: i) strength of the stone slab against the lateral load and the ii) strength at the fixing point.

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i) Calculation for the thickness of the stone slab compared to the lateral loading on the stone.

$W = (q \times b) / 10^6$

W = load in N/mm
q = pressure in N/m^{-2}
b = width in mm

$Mf = (W \times L^2) / 8$

Mf = failure moment in N.mm
W = load in N/mm
L = span in mm

$fb = Dfb / FSF$

fb = flexural stress in MPa
Dfb = design flexural stress of the stone in MPa
FSF = flexural safety factor

$S = Mf / Fb$

S = section modulus in mm^3
Mf = failure moment in N.mm
f b = flexural stress in MPa

$$d = \sqrt{\frac{6S}{b}}$$

d = thickness of the stone in mm
S = section modulus in mm^3
b = width in mm

ii) Calculation to check the Strength at fixing point

Wind Load $N.m^{-2}$ (see Table 2) x Panel Area m^2 (b = width in mm x L = span in mm)/10^6x factor of Safety (see section 4) = Lateral load on the stone panel.

Lateral Load on the Stone Panel ÷ Number of Fixings = Loading on each Fixing.

The loading on each fixing needs to be compared with the result for the breaking load at dowel hole for the appropriate thickness. The loading needs to be significantly less than the strength.





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Example of Stone Thickness Determined by Calculation

Below is an example of the stone thickness calculation using Portland Jordans Basebed with a panel size of 900 mm long (l) and 600 mm high (b) and 4 dowels fixings supporting the stone. It is assumed that the building is in Central London, but a wind load calculation has not been completed so the figures in Table 2 have been used for a low wind environment so the load is 1500 N.m^{-2} (q). The mean flexural strength figure of 6.78Mpa (Dfb) has been used and a factor of safety of 6 (FSF) for the lateral loading and strength at fixing calculations.

1. *Calculation for the thickness of the stone slab compared to the lateral loading on the stone*

   W = (q x b)/10^6
   W = (1500 x 600)/10^6 = 0.9

   Mf = (W x L^2) / 8
   Mf = (0.9 x 900^2)/8 = 91.125

   fb = Dfb/FSF
   fb = 6.78/6 = 1.13

   S = Mf/Fb
   S = 91.125/1.13 = 80,642

   $$d=\sqrt{\frac{6S}{b}}$$

   d = √6 x 80,642/600 = 28.4

   A Portland Jordans Basebed panel of 900 mm x 600 mm in Central London needs to be 28.4 mm (say 30 mm) thick to resist lateral loading.





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2. *Calculation to check the strength at fixing point*

Wind Load N.m^{-2} (see Table 2) x Panel Area m² (b = width in mm x L = span in mm)/10^6 x
factor of safety (see section 4) = Lateral load on the stone panel

Lateral load on the stone panel = 1500 x (600 x 900)/10^6 x 6 = 4,860 N

Lateral Load on the Stone Panel ÷ Number of Fixings = Loading on each Fixing

Loading on each Fixing = 4,860/4 = 1,215 N

Portland Jordans Basebed Dowel Pull tests show that;

- *40 mm the mean breaking load is 1,138 N*
- *50 mm the mean breaking load is 1,637 N*

Therefore, to allow for a significant margin in the fixing loading strength of the Portland Jordan Basebed stone panels of 900 mm x 600 mm, the thickness needs to be 50 mm.

The calculations show that to resist the lateral loading the thickness needed to be 30 mm thick, but to provide a suitable strength at the fixing point the thickness needed to be 50 mm. Obviously the greatest thickness figure of 50mm needs to be used.



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Stone Thickness determined by the tables in Annex A

The tables in Annex A are to be used for stones that have an excellent record of previous use in a similar environment as defined in test Regime 1 in Table 3 Part 1, and also the information in the History of Use section in these notes under section 1, Geology and Samples.

As the stone's flexural strength is the only figure considered, apart from the span between fixings, it is vital that the stone selected has adequate and current technical data results tested to the correct Euro-code testing Standard with a CE Certificate, also see Section 1 and 2 of these notes. These data sheets/certificates will provide the figures for the flexural strength either as a mean figure or a lowest expected value (LEV); it is the mean figure that is required for these tables. Stones that have a large number of reliable test results over a long period will provide the most dependable mean figures. Most stones will suffer some strength reduction when tested wet, so the wet test results will provide the most conservative strength values.

Table 1 – Panel thickness for high wind load environments

Greatest span between fixings mm	Panel thickness based on mean flexural strength mm			
	1.00 MPa to 2.99 MPa	3.00 MPa to 8.99 MPa	9.00 MPa to 14.99 MPa	> 15.00 MPa
> 300	50	40	30	30
300 to 450	70	50	30	30
451 to 600	80	60	40	30
601 to 750	—	70	40	40
751 to 900	—	80	50	40

Table 2 – Panel thickness for medium wind load environments

Greatest span between fixings mm	Panel thickness based on mean flexural strength mm			
	1.00 MPa to 2.99 MPa	3.00 MPa to 8.99 MPa	9.00 MPa to 14.99 MPa	> 15.00 MPa
> 300	50	30	30	30
300 to 450	60	40	30	30
451 to 600	70	50	40	30
601 to 750	80	60	40	30
751 to 900	—	70	50	40

Table 3 – Panel thickness for low wind load environments

Greatest span between fixings mm	Panel thickness based on mean flexural strength mm			
	1.00 MPa to 2.99 MPa	3.00 MPa to 8.99 MPa	9.00 MPa to 14.99 MPa	> 15.00 MPa
> 300	40	30	30	30
300 to 450	50	40	30	30
451 to 600	60	40	30	30
601 to 750	80	50	40	30
751 to 900	—	60	40	30

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6. Impact Resistance

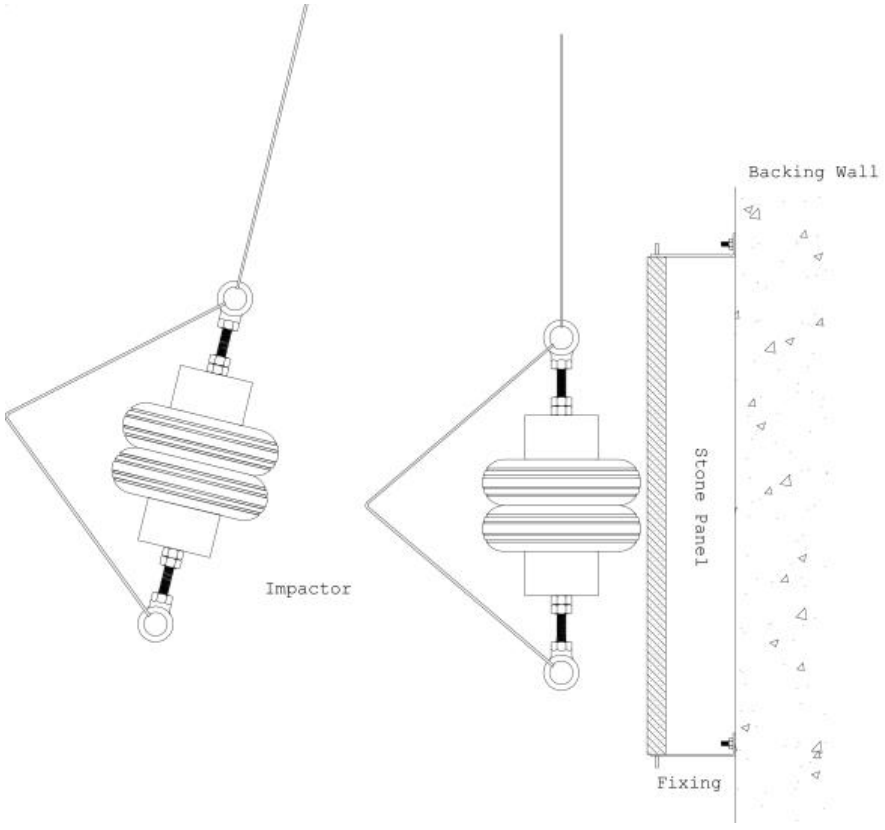
Note: Stone Federation is developing and undertaking a comparative research project to evaluate the 'old' bag impactor with the 'new' double tyre impactor and the results will be included in the next revision. The section 6.14 in Part 4 explains that the soft body impact is the relevant risk for cladding and the test seeks to represents a person falling against or walking into a stone panel.

For the testing, the stone panel should be the same size, thickness and finish as the proposed project, the same fixings must be used and the supporting structure must be of equal or greater stiffness.

The impactor defined in BS EN 12600 is the 'double tyre' and weighs 50 kg. It is suspended in front of the stone panel, within 15 mm of the impact point but not touching and is drawn back, so that the centre of gravity rises by a pre-determined amount (the 'drop height'). The impactor is released and allowed to swing freely into the stone panel and caught before it strikes the panel a second time.

The drop height is selected according to the expected risk of a stone panel being impacted in service.

A panel may fail either by bending (typically when struck at the centre, or near the middle of an edge), snapping off a corner (when impacted at the corner) or by the fixing punching through the front face (when impact is near a fixing point). A given panel size will need to be tested at several locations – the designer needs to know which is the worst case. When designing the thickness of the stone and the fixings, the requirements of Table 10 in Part 4 'Risk of impact' must be considered.



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