

Structural aspects of cladding

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Foreword

The Institution of Structural Engineers first published *Aspects of cladding*¹ in 1995, aimed at all building envelope stakeholders. This publication draws heavily on that guidance, but has been brought up to date to reflect the increased complexity of the subject, and has been written primarily for a structural engineering audience, to assist in preparing the structural design of a cladding system and the structural design of the primary structure supporting it.

Most buildings require some form of cladding. Until relatively recently this was either in masonry or asbestos cement sheeting form. Then came profiled metal sheeting and today we have a wide range of materials and systems. I have no doubt that more systems will come onto the market as material technology develops further. Cladding is a complex subject and we have, in this guide, attempted to identify the main points of concern to the structural designer. However, other built environment professionals will also find value in the guidance — particularly the extensive chapter on systems.

The guidance focuses on methods of cladding and systems currently available, with the loadings, design and details for each type. Included also, where appropriate, is advice and guidance gained from the experience of the contributors.

Many lessons of the 2017 Grenfell Tower fire in London have yet to be established and codified. We have included advice we think appropriate at the time of publication, but the designer is advised to keep up to date on matters pertaining to fire and any requirements that may arise in the future.

I would like to thank the members of the Task Group for their efforts in compiling this guidance, especially their employers which include Arup, BuroHappold, Ramboll, Thornton Tomasetti, the University of Southampton and the CWCT (Centre for Window and Cladding Technology) together with Rob Thomas and Lee Baldwin of the Institution for their unstinting help and guidance.



Nick Eckford
Task Group Chair

1 Introduction

Many factors influence cladding design — weather-tightness, durability, thermal transmittance, sustainability, maintenance, acoustic performance, solar shading performance, fire performance, structural integrity, function of the building and architectural appeal and, considering these, designers often need to think innovatively.

This guide is a broad introduction to cladding systems and materials for design engineers, acting for either the principle envelope designer or the supplier. It mainly refers to British and European standards.

Various forms of cladding systems and materials are considered, together with the structural issues relating to them.

The terms ‘facade’ and ‘cladding’ are, to a large extent, interchangeable and both are used here.

1.1 Design

Cladding is the building envelope — it protects and contains the building structure and the useable spaces within. It can take many different forms and is usually supported by the primary building structure but may also form part of that structure. There are exceptions to this where, for example, the building structure is partly exposed outside the cladding.

It becomes even more complex when a system is imposed on an existing building with the intention of improving the properties of the cladding or altering the appearance.

There are many ways of constructing a building envelope, involving several design and construction disciplines. Traditionally, a structural engineer of the primary structure may not have been involved in the envelope design, but as systems have become more sophisticated this primary structural input has necessitated coordination in the design of cladding systems.

The scale of the units and forces from and within the cladding system may well be in an order of magnitude smaller than those for the primary structure. Cladding is generally built to much tighter tolerances than building structures and is typically rigid in plane. It is essential that the structural designer understands the properties and limitations of the materials used and the relationship between the building and the cladding.

The design needs to be such that:

- The client and architect can be confident that the design meets the requirements of the brief
- The structural engineer (primary and envelope) understands how the primary structure supports and interacts with the cladding
- The main contractor understands the structural principles of the cladding, ensures and facilitates information transfer between the designers and can ensure the final detailed design is appropriate
- All parties understand and ensure that every aspect of the design is considered, especially where secondary structures between the cladding and primary structure are required

The procurement method employed will influence the responsibility of the various designers. Generally, the design team defines the overall intent and the supplier provides the final structural justification. Lack of understanding and/or significant changes to the structure and the cladding after they have been defined for design may result in cladding or fastenings that are not fit for purpose.

Eurocode practice is to refer to loads as ‘permanent actions’ and ‘variable actions’, rather than ‘dead loads’ and ‘live loads’. The Eurocode terminology is used in this guide.

1.2 Regulation

At the time of publication, several enquiries into the 2017 Grenfell Tower fire in London were ongoing — notably the Hackitt review and report². A revised set of Building Regulations in England and Wales will be published in due course, while an updated Approved Document B³ was issued in 2019, with further revisions anticipated. This will influence many matters of design, not least cladding, and could mean that insurers impose more onerous requirements on cladding products.

1.3 Roles and responsibilities

The parties involved in the procurement and final design of the building envelope may include the following:

- Client
- Architect
- Structural engineer responsible for the primary structure

- Contractor's design engineer for the primary structure
- Contractor's cladding package manager
- Cladding consultant or party responsible for the design intent of the cladding
- Engineers responsible for the final detailed design of the cladding
- Specialist subcontractors or suppliers for the different components
- Access consultant

While the designer of the primary structure may define the cladding system and determine how it fits with the rest of the building, it is important that they are also aware of the detailed proposals and ensure that these are compatible with the primary structure.

It is the responsibility of all designers to coordinate their portion of the design with interfacing element designers and so ensure that the designs are competent and cover all project requirements.

While the original design is undertaken by the architect and primary structure engineer, the detailed design will usually be prepared by the specialist cladding contractor or a subcontractor. Coordinating the requirements of the detailed design and the supporting structure needs to be carried out by persons who understand the requirements of both. These people should be able to review, and check if necessary, the details of the systems, especially when, as is common, the systems are designed and detailed by a subcontractor.

2 Actions on cladding

2.1 Introduction

The basis of structural design of non-loadbearing cladding shares many similarities with the structural design of the primary building structure. Cladding is required to carry its own weight as well as any loads applied directly to it. However, in most cases it does not contribute to the strength or stiffness of the primary building structure.

The principles defined in BS EN 1990⁴ also apply to the structural design of cladding, which should be designed to safely transfer the loads (and combinations of loads) applied to it, to its support locations at the ultimate limit state (ULS) and should retain its intended levels of performance when loaded at the serviceability limit state (SLS).

Due to the large range of materials and components used in cladding, their exposure to the elements and use at height, it is often critical to assess post-failure behaviour under accidental or extreme loads. This requires consideration of progressive collapse, falling components and ease of repair to restore the cladding to a safe and serviceable state.

The loading principles defined in BS EN 1991^{5–11} also apply to non-loadbearing cladding. However, there are often challenges in interpreting such loads and their applicability. There are often differences in the magnitude and physical application of loads applied to cladding in contrast to loading on the primary structure.

This chapter highlights a number of these challenges and illustrates ways of addressing them where possible.

The Centre for Window and Cladding Technology (CWCT) is a rich source of information on all aspects of cladding design and construction. The loads described in this chapter follow the principles and definitions given in BS EN 1990, BS EN 1991 and CWCT *Guidance on the actions on non-loadbearing envelopes*¹². Unless otherwise stated, loads given refer to characteristic, or unfactored loads. Reference should be made to the CWCT guidance for further information on partial factors of safety and load combinations.

2.2 Design life

The general design life of a building is taken to be 50 years. While structures may well last longer than this, it is likely that the building will undergo at least one

refurbishment during this period. Cladding is designed to suit the building and will be expected to be designed to the 50-year life expectancy. It is possible that some components of the cladding, such as membranes and sealants, are unlikely to last this period and have a shorter effective life. This should be made clear in any maintenance manual.

2.3 Applied loads

2.3.1 Permanent actions

The self-weight, or permanent actions of cladding is the most fundamental load to be accommodated by the cladding structure and its supports. Since cladding can be manufactured from several different components, one of the most critical aspects in considering permanent actions is the internal load transfer from individual components through to the supporting bracketry. Care should be taken to include the load from components that may be added to the cladding at a later stage, such as signage or external shading.

This load transfer may not always be immediately intuitive since variations in localised stiffness, movement accommodation and tolerances may influence the true load path. This is particularly important when using brittle materials such as glass, ceramics or stone, to avoid unintended material contact and stresses — though it can also be relevant when considering load transfer in more heavyweight precast concrete panels, where loads need to be effectively transferred to the primary structure.

Allowance for the effects of temporary orientation, stacking of components, lifting and transportation should be made. In the design, consideration should be given for any change in the load paths if the primary structure moves.

BS EN 1990 and the UK National Annex¹³ recommend an ULS partial load factor of 1.35 for permanent unfavourable actions. Annex C of BS EN 13830¹⁴ suggests that a lower factor of safety of 1.15 may be used for curtain walling framing due to a lower consequence of failure when compared to components of the primary structure. However, CWCT guidance recommends that a class of consequence reduction factor is not applied and that a reduction of partial load factor for permanent actions is only considered when:

“the exact weight of components (saturated if appropriate) is known and their position on the building envelope is controlled. When the ultimate limit state is

checked, both extreme tolerances for position and component dimensions should be considered in calculations. Rigorous site monitoring is required to ensure tolerances are not exceeded.”¹²

Unintended load paths may not only influence the ULS but also serviceability, particularly when operable components are included in cladding elements. These may become jammed even with relatively small movements of the primary structure and/or the cladding.

It is worth noting that turbulent wind conditions may exist around buildings — creating local wind excitation frequencies higher than would be considered for primary structure elements. It is recommended that protruding elements, in particular, should be reviewed to consider their natural frequencies in the context of these potentially higher driving frequencies.

2.3.2 Wind loads

Due to their external nature, wind loading will impact on all cladding elements, and is often the governing applied load. Wind loads can be measured in wind tunnel tests or calculated in accordance with BS EN 1991-1-4 and the UK National Annex¹⁵. PD 6688-1-4¹⁶ contains information that is particularly relevant to cladding wind loads, including:

- Re-entrant corners and recessed bays
- Irregular or inset faces
- Canopies attached to tall buildings
- Open-sided buildings
- Directional methods

The CWCT *Standard for systemised building envelopes*¹⁷ recommends the use of 800Pa as a minimum characteristic wind load for the purposes of robustness, and that horizontal zoning of wind pressures along the height of a building is not carried out for cladding loads, because localised peaks of wind pressure may occur further down the building surface, carried downwards by downdraughts. Wind loading acting on cladding is generally higher than the loading on the primary structure, as cladding components are significantly smaller than the structure. The effects of proximity to sharp corners will also affect wind loads and protuberances such as balconies can increase local wind loading. All of these effects are likely to result in higher cladding wind loads when compared to the wind loading on the building structure as a whole. This will influence the design of cladding and the support brackets to the structure.

Particular care should be taken when calculating wind loads on layered walls or roofs. Although there will generally be an element of shelter provided by one surface at any one point, the dynamic nature of wind

loading means that load share on a particular surface can vary over time. Guidance on this aspect is given in BS EN 1991-1-4 and CWCT *Guidance on the actions on non-loadbearing envelopes*. Most guidance on wind loading on layered walls assumes that cavities at the corners of buildings are closed off. It is therefore recommended that cavity corner details are designed to significantly limit air flow in layered walls, such as rainscreen systems or double-skin facades, unless specialist advice is sought.

Another area that offers a particular challenge is the calculation of wind loads for external cladding components which are exposed to wind on both faces. These can take the form of shading elements, canopies, tall parapets or cladding elements set at a distance from the main building volume. When conducting wind tunnel testing, laboratories should be advised of these elements, to ensure that adequate instrumentation is provided on the scaled models to calculate the net differential pressures acting on these geometrical features. It may also be possible to calculate estimated net pressure by considering the expected loads on similar features, such as canopies, free-standing walls, parapets or sign boards, which are covered by Clauses 7.3 and 7.4 of BS EN 1991-1-4. Vertical or horizontal shading elements close to building corners can act in an aerodynamically similar fashion to protruding roofs, which will attract significant local wind pressures. Vertical elements are particularly vulnerable to the higher wind speeds that occur at building corners. Further recommendations are given in *Guidance on the actions on non-loadbearing envelopes*.

Cladding components may be subjected to increased pressure on their internal faces which may not be immediately obvious. This often occurs temporarily during construction until the cladding of an entire floor is completed, temporarily generating a wind loading case of an open-sided building. This is considered in PD 6688-1-4 and, where relevant, seasonal factors can be considered to reduce the calculated wind loads.

A similar scenario is where dominant openings may exist in the building envelope, which will significantly increase internal pressures. BS EN 1991-1-4 recommends that an accidental load case is considered, where opening elements would be dominant when left open during a significant storm, but is considered as closed in the ultimate limit state. Similar effects may also occur due to glass breakage from wind-borne debris in locations where wind speeds are very high, such as regions influenced by hurricanes.

2.3.3 Snow and ice loads

Snow loading is not commonly associated with vertical facade loads. However, this can sometimes be a

significant applied load, particularly on horizontal shading, canopies and glazed roofs. It is possible to simulate snow loading in a specialised wind tunnel test but these are more frequently calculated in accordance with BS EN 1991-1-3 and the UK National Annex¹⁸. Cladding can also be influenced by snow drifting, although this is often considered an exceptional load case, in line with BS EN 1991-1-3 Annex B.

BS EN 1991-1-3 does not consider either loads due to ice, or additional wind loads resulting from changes in shape of building elements. These effects are rarely governing factors in occupied and heated buildings. Although written for steel towers and masts, some relevant guidance is provided in BS EN 1993-3-1 Annex C¹⁹ and ASCE 7²⁰.

Under particular conditions, it may also be relevant to consider lateral loading on vertical facades due to snow drifts.

2.3.4 Occupancy loads

Occupancy loads on cladding can often govern material selection, particularly where this forms the only barrier to building occupants falling from height. BS EN 1991-1-1, the UK National Annex²¹ and PD 6688-1-1²² give applied loads for different scenarios, varying from residential loads to areas susceptible to over-crowding. Further requirements on barriers in and about buildings is given in BS 6180²³ and Building Regulations Approved Document K²⁴. These occupancy loads are classified as area loads, line loads and point loads which represent different ways in which the occupants may push onto the barriers. However, it should be noted that these loads should not be applied simultaneously. CWCT's *Guidance on the actions on non-loadbearing envelopes* recommends that point loads are applied over a square 100mm x 100mm in size and line loads applied over a strip 100mm wide, where applicable in finite element modelling.

Although it may be relatively straightforward to extract the loads from these documents, further care needs to be taken in considering safe breakage (and containment of occupants in the event of breakage). This is particularly relevant for glazed barriers and glazed roofs²⁵⁻²⁷.

*Guide to safety at sports grounds*²⁸ also gives recommended loads in stadia where crowd loads can reach very high levels.

CWCT TU 14²⁹ may be considered, when crowd and wind loads might act at the same time.

2.3.5 Maintenance loads

Maintenance loads applied to cladding may occur due to a number of cleaning, maintenance or replacement activities (also see Section 2.3.12) including:

- Maintenance loads on roofs
 - The UK National Annex to BS EN 1991-1-1 gives this as 0.6kN/m² or 0.9kN for point loads on flat roofs
- Loads from ladders
 - CWCT *Standard for systemised building envelopes* recommends 500N applied over a square with 100mm sides
- Footfall and rope reactions from abseilers
 - This is not governed by standards and must be specified by the access consultant during the design phases to make sure that these loads can be accounted for by the design team
- Restraint and snagging loads from building maintenance unit (BMU) cradles
 - Restraints are often provided within cladding elements for BMU cradles in accordance with BS EN 1808³⁰, in order to limit the maximum swing of the cradle when subject to wind. The restraint reactions are not given directly in BS EN 1808 but they can be calculated on a case by case basis, depending on the expected dynamic swing from the cradle in accordance with CWCT TN 96³¹
 - Unintended snagging of a cradle in transition may occur when localised projections are present in the cladding design. CWCT TN 96 provides recommendations on limiting the effects of snagging through appropriate BMU cradle design
- Impact loads
 - Impact loads are covered in more detail in Section 2.3.11

2.3.6 Fit-out loads

Fit-out loads are not usually considered in cladding design unless explicitly stated in project specifications. This is partly due to invalidation of warranties if drilling into curtain walling, or if other modifications are carried out which have not been explicitly designed for.

Where fit-out loads are expected in dry lining, which may be installed inboard of the main cladding system, care should be taken to minimise the risk of puncturing vapour barriers. BS 5234-2³² gives loads for internal fixtures which can reach 4kN at an eccentricity of 300mm for wall cupboards.

2.3.7 Fire loads

Although fire does cause loading to cladding, through extreme temperature and the resulting material expansion, these loads are not usually considered as part of regular static calculations. Instead, attention is drawn to the sequence of failure in the case of fire. This often means that connection points to the primary structure remain robust under fire load, and will either be protected against fire, or be protected at least to the same extent as the remainder of the cladding. It may

require attention to detail to ensure that any connections made for the cladding do not, for example, affect the continuity of intumescent coatings on primary steelwork. This is particularly relevant to cladding with a high resistance to fire, such as precast concrete. However, consider incorporating relevant fire protection for bolt-on balconies to avoid their collapse.

This sequence of failure is particularly important for cladding over key escape routes and locations of firefighter entry. In some instances, it may be necessary to protect these main entry points from falling debris.

Consider the possible effects of any gap between structure and cladding, vertical and horizontal, that allows the passage of fire, or smoke, between fire compartments. Gaps and cavities can act as a chimney, with protection generally required to any penetrations of the cavity, such as windows. The cladding may well be required to be fire-resistant and to prevent fire spread.

When fire-rated curtain walling is required to have a specific structural or insulation-resistance to fire, tested systems should be used. Note, where full-scale tests are carried out, these should be fully representative of the design scenario for the building to be constructed.

2.3.8 Security/intruder loads

The matter of security really only applies to those elements that are accessible from the exterior — ground floor elements and areas that can be accessed from nearby buildings. Most types of cladding are inherently capable of resisting penetration, but where lightweight systems are used, the matter of penetration, in order to gain access should be considered, particularly for operable elements^{33–34}.

There will be access points and doors into the building and these will require appropriate consideration. BS EN 356³⁵ gives relevant testing for glass elements. Where a 'ram raid' type of attack might occur, this should be accounted for in the design of elements that may be exposed to this.

2.3.9 Blast loads and ballistic attack

There may be a requirement that the building is able to resist possible blast loads, so any building subjected to such loads should protect its occupants, and may be required to remain serviceable.

The cladding of a building is the first line of defence for protecting occupants from external blast loading. Consideration of the performance of cladding is primarily a life safety issue. Designing the cladding to withstand blast loads prevents failure of the cladding, debris from being thrown into the building and limits blast ingress.

Cladding in these circumstances may also protect the primary structure but, in doing so, will also increase the loads that are imposed on it.

Design of blast-resistant cladding is one of many potential blast-resistant measures that can be used throughout a building. The design requirements should never be determined in isolation but as part of a holistic Threat and Vulnerability Risk Assessment (TVRA) process.

It is expected that the TVRA will determine an appropriate threat level and a range of performance criteria and potential mitigation options for the site and the building, one of which may be blast-resistant cladding. A decision is required by the client to determine the required level of performance for an appropriate threat level. Only then is it possible to determine the design level blast loads that the cladding should be designed for.

Design of the blast-resistant cladding should be performed by a suitably qualified blast engineer. Dynamic, nonlinear analysis is preferred over elastic static design methods, as the latter generally produces an overly conservative design. Use of nonlinear design methods accepts that damage occurs and that the engineer can take advantage of energy absorption through plastic deformation.

In the UK, it is advised that suitable experts are sought from the Register of Security Engineers and Specialists (RSES). Advice should also be sought from the relevant local police authority Counter Terrorism Security Advisor (CTSA).

Ballistic attack will be by methods designed to penetrate armoured enclosures. It is unlikely that design for this in building cladding will be required. However, several curtain wall cladding and glass suppliers can accommodate these special requirements and should be consulted at an early stage.

2.3.10 Seismic loads

In many countries affected by earthquakes, cladding systems (including glazed facades, solid walls, shading devices, balustrades and canopies) must be designed to accommodate the movements of the primary structure and the movements between the cladding elements. Seismic loads on the structure can potentially impose significant in-plane loading on the cladding systems and may lead to damage if adequate detailing is not provided. The performance of any cladding system under a seismic event is dependent on the amount of drift, and the interaction of the cladding panel with the support structures.

Structural engineers design the primary structure depending on the form of the building, its geographical location and ground conditions. International or regional seismic codes such as BS EN 1998-1-1³⁶ and the UK National Annex³⁷, the International Building Code³⁸, ASCE 7, JASS14³⁹, FEMA P-750⁴⁰ or NZS 1170.5⁴¹ describe how to calculate the seismic horizontal force for non-structural elements and define the permissible inter-storey drift for buildings, depending on the structure type and risk categories (typically between 1/500 and 1/200 of the storey-height) using elastic or inelastic approaches with static or dynamic analyses. The shear and rotations induced by seismic loads must be determined by the structural engineer to guide the design of the cladding.

Cladding should be designed with the same principles of the building structure against ultimate and serviceability state. Generally, cladding and glazing are required to remain safe under the ultimate state (upper earthquake event). Any facade members (i.e. framing, cladding brackets and associated fixings) are expected to withstand inertia forces due to acceleration of the building arising from seismic sway — retaining its structural integrity and a residual loadbearing capacity after a seismic event. Partial dislodgements and permanent deformations are often allowed for in secondary facade elements only (i.e. beads, internal decorative elements) but all are retained in the framing/supporting elements. Clarity must be obtained at an early stage on any requirement for glazing to remain in place after a seismic event.

For the serviceability state, it is often allowed that drainage paths, waterproofing membranes, open or sealed joints, window/louvres/vent operation could be affected by the earthquake and that weather-tightness may be compromised. It is essential to manage expectations with the client and establish the anticipated post-event performance of the cladding with regards to weather-tightness, building down-time and cost to repair. Definition of the movements of the primary structure at serviceability and safety levels are key in the successful design of cladding under seismic actions. This may not be straightforward, as structural design codes are often focused on ultimate structural safety. Definition of the levels of performance and return periods often need to be agreed in detail at an early stage of design, to coordinate the magnitude of structural movement with cladding performance, particularly at different serviceability states.

The facade engineer has to use the allowable inter-storey drift provided by the structural engineer to detail the cladding systems accordingly. Movement could be accommodated by rotation, shearing or sliding of panels. In case of moment frame structures, the structural

engineer for the primary structure should provide more detailed information so that the vertical beam movements associated with moment frame resistance are also set out.

In order to validate how the cladding system actually reacts to the structural movement induced by the seismic design conditions, specialist racking testing of the facade systems can be specified to test the impact of the seismic movements¹⁷.

For more information refer to CWCT TN 30⁴².

2.3.11 Impact loads

Impact loads may be internal or external and can arise from general use, or from flying debris in a storm or accident.

Impact loading is a specialised area of design for cladding, and is mostly verified through full-scale testing, due to the dynamic nature of the loading and the sensitivity to small details and construction tolerances which can significantly influence results. Although not common practice, it may be possible to undertake calculations to demonstrate performance levels e.g. where existing test data is being interpolated to demonstrate compliance, or where a significant body of test data is available, such as impacts on safety glass.

Impact loads are expressed as impact energy (Joules), alongside a test methodology which defines the type of impactor. Five types of impactor are commonly used in facade testing:

- Double tyre impactor for soft body impact on glass only (BS EN 12600⁴³)
- Spheroconical leather bag filled with glass beads (CWCT TN 76⁴⁴)
- Steel spheres of different diameters (BS EN 356 and CWCT TN 76, or axe test to BS EN 356)
- Full-scale cleaning cradle mock-ups (where standard impactors are deemed unrepresentative)
- 2" x 4" timber of different lengths — for hurricane regions only (ASTM E1996⁴⁵)

Test methods and sequences are given in the following documents:

- Hard and soft body testing on opaque cladding systems (CWCT TN 76)
- Hard and soft body testing on frames and cladding elements (BS EN 14019⁴⁶)
- Hard and soft body testing on window elements (BS EN 13049⁴⁷)

Impact energy can sometimes govern design of certain elements of cladding design. Steps can be taken in the

maintenance strategy to mitigate the applied impact energy that could be applied to the cladding e.g. by introducing additional restraint points for cleaning cradles or limiting the maximum environmental wind speed at which maintenance operations can take place. Several aspects of material selection however, will still be governed by the applied impact energies, particularly when considering brittle materials such as ceramics, glass and stone.

Impacts are often specified as both serviceability and safety impacts. The former is meant to represent frequently occurring activities, while the latter represents more extreme events. Factors of safety are not usually applied to specified impact energies and these are tested with the energy specified. CWCT TN 75⁴⁸ defines classes of performance for serviceability and safety, shown here as Tables 2.1 and 2.2. When specifying test pass/fail criteria, consideration should be given to material selection as well as the level of performance requested. Certain brittle materials are known to be sensitive to impacts, particularly hard body impacts. In some instances, it may not be possible to pass a test without fracture. A similar argument holds for materials of

different hardness. For example, a solid steel ball will generally dent a thin aluminium sheet at high impact energies.

Several standards exist for impact testing of cladding, ranging from material standards e.g. BS EN 12600 for glass, to whole system testing e.g. BS EN 14019 for curtain walling. The precise requirements for a project may be complex and it is recommended that project-specific specification of impact testing is prepared. This should outline the test method, number of tests, location and number of repetitions required. These tests are carried out on full-scale prototypes and the number of tests specified may become very large and uneconomical. It is sometimes possible to use existing test data for certain products when these are comparable to application on-site, as determined by an engineer with suitable experience. Where this is not possible, it is recommended that the number of tests is proportionate to the extent of material used on-site and the risk posed to the public, the building occupants and the building owner. CWCT TN 75 and TN 76 give recommendations on the various tests to be considered.

Table 2.1: Classes for serviceability performance

Class	Definition	Explanation/examples
1	No damage	No damage visible from 1m, and Any damage visible from closer than 1m unlikely to lead to significant deterioration
2	Surface damage of an aesthetic nature which is unlikely to require remedial action	Dents or distortion of panels not visible from more than 5m (note visibility of damage will depend on surface finish and lighting conditions — damage will generally be more visible on reflective surfaces), and Any damage visible from closer than 5m unlikely to lead to significant deterioration
3	Damage that may require remedial action or replacement of components to maintain appearance or long-term performance, but does not require immediate action	Dents or distortion of panels visible from more than 5m, or Spalling of edges of panels of brittle materials, or Damage to finishes that may lead to deterioration of the substrate
4	Damage requiring immediate action to maintain appearance or performance Remedial action may include replacement of a panel but does not require dismantling or replacement of supporting structure	Significant cracks in brittle materials e.g. cracks that may lead to parts of tile falling away subsequent to test, or Fracture of panels causing significant amounts of material to fall away during test
5	Damage requiring more extensive replacement than Class 4	Buckling of support rails

Note: Derived/adapted from CWCT TN 75⁴⁸.

Table 2.2: Classes for safety performance

Class	Explanation/examples
Negligible risk	No material dislodged during test, and No damage likely to lead to materials falling subsequent to test, and No sharp edges produced that would be likely to cause severe injury during impact, and Cladding not penetrated by impactor
Low risk	Maximum mass of falling particle 50g, and Maximum mass of particle that may fall subsequent to impact 50g, and Cladding not penetrated by impact, and No sharp edges produced that would be likely to cause severe injury during impact
Moderate risk	Maximum mass of falling particle less than 500g, and Maximum mass of particle that may fall subsequent to impact less than 500g, and Cladding not penetrated by impact, and No sharp edges produced that would be likely to cause severe injury during impact
High risk	Maximum mass of falling particle greater than 500g Cladding penetrated by impact Sharp edges produced that would be likely to cause severe injury during impact
Note: Derived/adapted from CWCT TN 75 ⁴⁸ .	

Assessment of flying debris is not a common requirement in the UK and Europe. However, this can be critically important in regions with very high wind speeds, and particularly those that experience hurricanes or similar events. Performance is typically assessed using timber projectiles in accordance with ASTM E1996.

2.3.12 Impact by cradle or other access equipment

In many cases, the most considerable impact loads that vertical cladding will be subject to during its service life will be some form of maintenance activity. The most common impact considered is that from cleaning cradles hung from building maintenance units. Other forms of impact, such as abseilers' footfall are very difficult to reproduce reliably and are generally of smaller magnitude. These are commonly addressed by using an equivalent static load to give sufficient robustness to point loads on localised cladding elements.

CWCT TN 96 gives a dynamic method for calculating impact energy due to potential swing of a cradle in the wind. This impact energy can then be used in a test on a full-scale cladding prototype, using either a double tyre impactor⁴³ or a prototype of the actual cradle proposed for the building. If the latter is being used, it is essential that the buffers on the cradle prototype are identical to those used on the building.

Depending on the relative timing of testing and procurement, it is recommended to carry out tests using a representative cradle prototype. In such cases, judgement by an engineer experienced in such testing will be required to assess whether an impact using a

standard impactor will be reasonably conservative. Contractors may have facilities for such testing.

CWCT TN 96 acknowledges that it may be possible to perform a dynamic analysis to calculate an equivalent static load on the cladding. Currently however, data available on the dynamic material properties of cradle buffers is limited.

2.3.13 Impact loads on roofs

Roof impacts in relation to cladding are most commonly seen when assessing glass roofs. CWCT TN 66⁴⁹ and TN 67⁵⁰ provide a test method to assess the fragility of roofs, particularly when these can be accessed by maintenance operatives. Such testing is also required when operatives are not intended to walk on the glass, but could accidentally fall onto the glass while cleaning from a safe platform. This testing involves a sequence of hard and soft body impact tests to simulate an event when one person falls onto the glass, breaks all glass panes with their tools, and another person is required to assist the injured person on the same piece of glass.

Such testing can be disproportionately costly for small areas of roof glazing and CWCT TN 92⁵¹ provides recommendations on glass build-ups that are deemed to satisfy post-breakage requirements.

Glazing that is intended to be accessed by persons other than maintenance operatives is not covered by CWCT Technical Notes. Guidance on this is given in ASTM E2751⁵² which gives both a calculation method — introducing required redundancy with laminated glass

— as well as a testing method to assess performance. German standards DIN 18008-5⁵³ and -6⁵⁴ also give requirements for such walk-on glazing.

A further form of impact is hail. CWCT guidance¹² notes that this is not usually a design consideration in the UK, but large hail stones can form in certain regions. BS EN 12975-1⁵⁵ gives requirements for the assessment of photovoltaic panels in relation to hail impact, and BS EN ISO 9806⁵⁶ defines the size, mass and terminal velocity of different potential hazards from hail stones.

It is not only glass roofs that can be fragile. ACR[M]001⁵⁷ defines testing for non-fragility of profiled sheet roofing assemblies.

2.3.14 Thermal loads

The various materials used in buildings have different thermal expansion coefficients and, for cladding, their position in the build-up will influence their thermal movements. Elements towards the inner face will have a more stable temperature similar to that of the building environment, while elements at or near the outer face could well be exposed to direct sunlight or cold winds. The outer layers of cladding will experience greater variations in temperature than the inner layers, and this difference may well be enhanced by the inclusion of insulation in the build-up. The range of temperatures experienced in temperate climates is given in Table 2.3, although the figures should be taken as guidance rather than as absolute values.

2.4 Load factors and limit states

Whether the design is in accordance with permitted stress design or, more commonly, limit state design, the designer must make it clear which method is being used. For the latter, both SLS and ULS will be used. Partial load factors for the ULS will generally be in accordance with the recommended values. However, there may be circumstances where different factors are appropriate, and these should be agreed with the lead designers. Reference should be made to CWCT guidance¹² for further information of partial factors on safety and load combinations.

Table 2.3: Service temperatures in temperate climates

External surface temperature	Min.	Max.
Cladding, walling and roofing		
• Heavyweight, light colour	–20°C	50°C
• Heavyweight, dark colour	–20°C	65°C
• Lightweight (insulated), light colour	–25°C	60°C
• Lightweight (insulated), dark colour	–25°C	80°C
Glass		
• Coloured or solar control	–25°C	90°C
• Clear	–25°C	40°C
Internal room temperature	Min.	Max.
• Building in normal use	10°C	30°C
• Building empty or not in use	–5°C	35°C
Note: Derived/adapted from BRE Digest 228 ⁵⁸ .		

3 Interface with the supporting structure

3.1 Introduction and basic principles

There are numerous ways to transfer cladding loads to the primary support structure, using both common details and elaborate bespoke details. However, the basic principles of the connections will remain largely the same and are provided in this section.

Cladding forms panels that need to be supported so that the loads from them are transferred to the supporting structure in such a way that they are stable.

Typically, the vertical loads (generally permanent actions) are supported at one level and horizontal loads are supported at two levels (Figure 3.1). While primarily resisting the applied horizontal loads, the latter can take eccentric loads arising from the former.

This is where systems are storey-height, with vertical loads taken at the top or bottom supports (standing or hung) and the horizontal loads taken at both levels.

Where systems are a fraction of the storey-height, the panel is bottom-supported for vertical loads and this and

the upper edge needs support for the horizontal loads, which can be ensured by:

- panels being equal to the full width of the structural bay and using the columns (or similar vertical structure) to provide support (Figure 3.2a)
- providing a beam to support cladding panels between columns (Figure 3.2b)
- securing a subframe to the primary structure (Figure 3.2c)
- cantilevering off the edge of the primary structure, relying on vertical cantilevers to impose torsion on the supporting structure. This is not a common solution (Figure 3.2d)

Many systems, typically curtain walls or glazing, continue over several levels (Figure 3.3). The general principle is to take the vertical loads at the highest or lowest level and the horizontal loads at each structural level. Where the height of the assembly is great, movement joints may be inserted so that interim vertical supports are required. These are often referred to, especially in curtain wall glazing, as 'stick systems' (Section 3.1.3).

Where systems are continuous over several floors, with their full loading being delivered at the upper or lower level, it is likely that the system will be designed as a stick system. Particular attention should be paid to the method of accommodation of movement, which may require good rebate detailing between glazing and the cladding framing elements.

Occasionally the system is required to carry vertical loads from the primary structure, such as a roof.

Figure 3.1: Typical cladding support

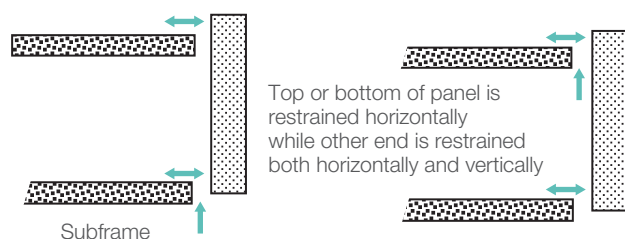


Figure 3.2: Typical part-height support

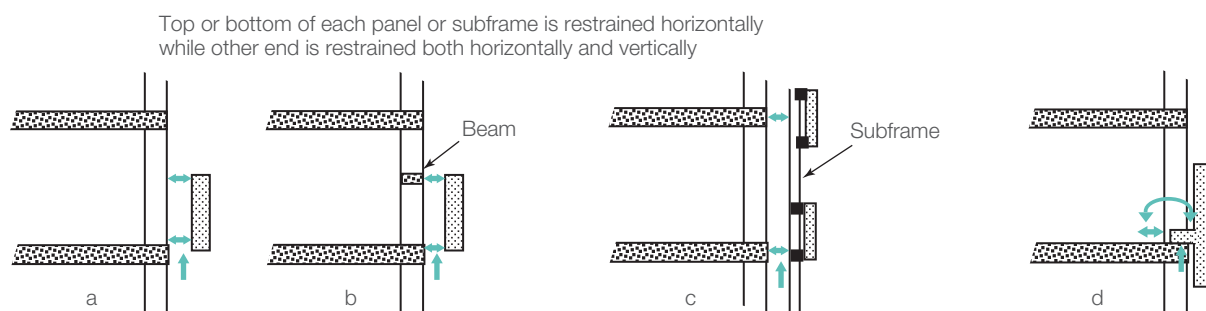
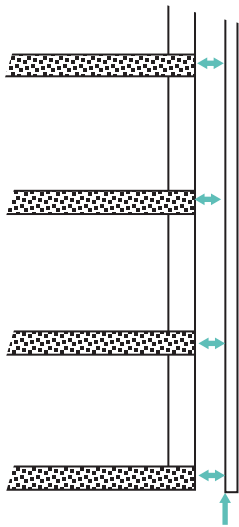


Figure 3.3: Multiple storeys support



It is essential that the cladding units are capable of transferring applied loads to fixing points without significant distortion. The fixing points must be robust enough to transfer loads to supporting fixings or brackets. The fixings or brackets will need to be strong enough to absorb the loads and have the necessary facility to accommodate any relative movement that may occur.

Due to the various forces on and within the cladding, it will move differently to the structure supporting it. This differential movement can often be absorbed by the designed-in movement accommodation of the fixings. However, where the cladding is of materials with different characteristics, the differential movements may be large enough to merit special consideration.

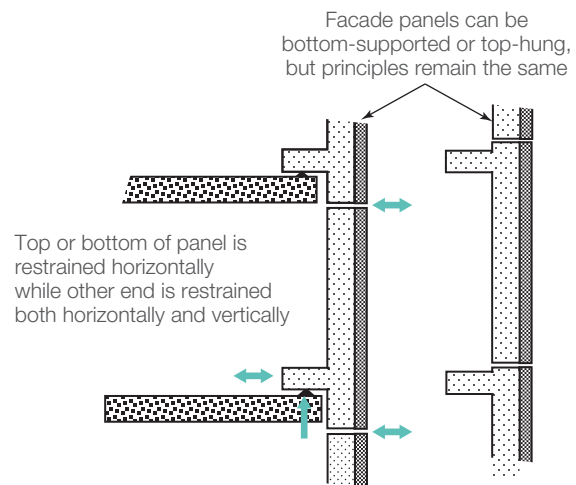
3.1.1 Full storey-height cladding

This will be either single skin brick outer leaf with a backing wall, concrete full-height panels or unitised systems. Precast concrete panels may also be loadbearing and form part of the primary structure.

Figure 3.4 shows that the panel is supported by a nib — this could take other forms. Any form of support will compromise the thermal and condensation performance. Through careful detailing however, by avoiding continuous supports, minimising the size of local discrete supports and including structural thermal breaks, this compromise can be minimised and made acceptable.

Usually the unsupported edge is the top edge in heavier systems, although unitised systems are generally 'hung'. The panels will need a restraining support at the unsupported edge — often provided by keying to the edge of the panel above or below, with allowance for vertical movement. This is important, especially with

Figure 3.4: Full-height panel support



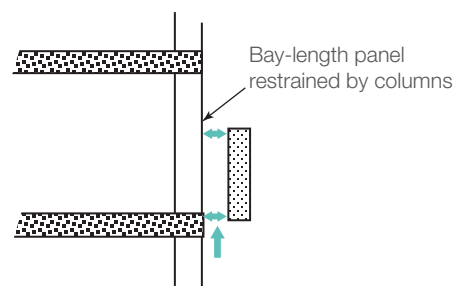
brickwork, as the panels will move significantly due to moisture and temperature changes, compared with the supporting structure.

Where the support is continuous, as with brick panels, the possible deflection of the supporting structure must be considered. Thin slabs may deflect appreciably, causing the panel to 'bridge' between stiff points in the support system and stress the panel. This is often counteracted by reinforcing the beds of the first few courses.

3.1.2 Part storey-height cladding

Figure 3.5 is a structural bay-length panel, typically concrete. The supports are generally set at each end, close to the vertical structure. The panel has sufficient strength to span the distance and support its own weight as well as the imposed forces.

Figure 3.5: Bay-length panel support

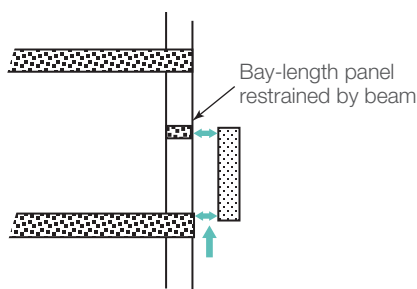


The panel, even if consisting of the same material, will move relative to the supporting structure. It will be exposed to the elements, so subject to a wider range of temperatures and, for concrete, shrinkage effects. Supports need to allow for possible relative movements.

Concrete panels will often have support brackets built-in (Fig. 3.4).

Figure 3.6 is partial height cladding with a top support, generally a beam. This is used where the cladding is in short panels or cannot span the bay distance between vertical supports.

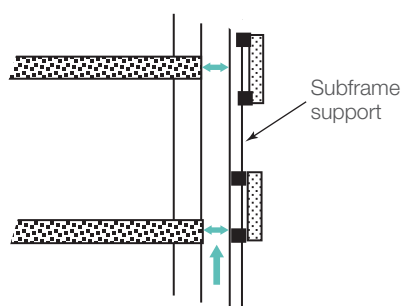
Figure 3.6: Bay-length panels with top support



Short panels supported on long spans may encounter several issues. The structural edge supporting the panels will deflect due to loads from the panels as well as internal applied loads, while the top beam will not be subject to these forces. Support systems need to be designed to accommodate these potential relative movements.

Figure 3.7 shows subframe-supported cladding. A subframe is employed where the cladding is formed of discrete panels, smaller than the vertical and/or horizontal bay. The subframe may extend over a number of storeys, with permanent actions supported once, and horizontal loads resisted at all support brackets. This type of support is often used with small panels such as ceramic tiles, which are hung on the subframe.

Figure 3.7: Subframe support



The subframe may be supported on a continuous wall, such as a concrete wall or infill blockwork in a concrete or steel structure. These walls need to be designed to take the forces imposed on them.

Where the cladding is generally not weatherproof, insulation and weatherproofing may be required between the subframe and primary structure. Rainscreen cladding uses this approach. Materials such as stainless steel and

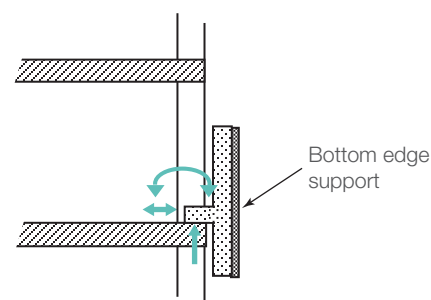
aluminium are preferred for the subframes, as these will endure for the working life of the building. In drier climates galvanised steel may be acceptable.

Brackets supporting the subframe should be designed to accommodate the possible relative movements. The cladding itself will be supported on the subframe.

It must be clearly established where the design responsibility lies for each aspect of this method.

In Figure 3.8 the cladding panel is supported entirely on one edge, generally the lower edge. All the forces from the panel are transmitted through the support brackets, as a combination of vertical loads and horizontally applied forces, which will result in force and moment on the support.

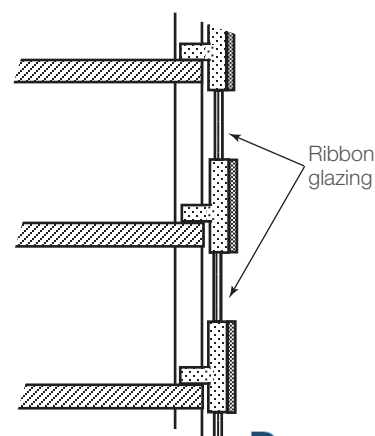
Figure 3.8: Lower edge support



Possible differential vertical movement between the support and cladding may need to be accommodated, and the panel could be much stiffer than the supporting structure.

This type of cladding panel can extend up and down from the slab, with ribbon glazing between the units (Figure 3.9). It may be necessary, if a stick system (Section 3.1.3) cannot be used, to support the glazing in such a way. Care must be taken when calculating

Figure 3.9: Ribbon glazing



the forces to include for the glazing and possible out-of-balance of the horizontal forces.

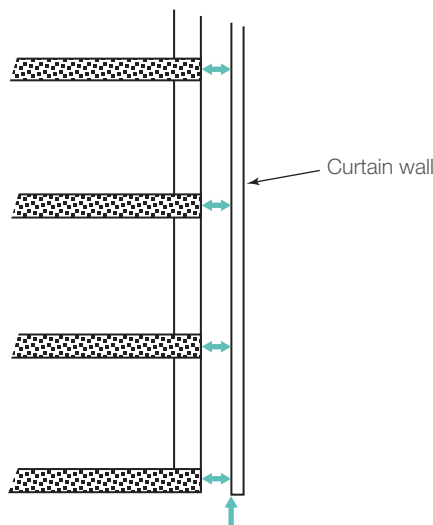
All systems will have variations in detail, depending on the type of cladding. In concrete-faced panels with brick slips as facing, the backing provides the structural element, while the facing is stuck on, often literally, and has no bearing on the strength of the panel.

Brick slips and their adhesives can be problematic and their use is generally not recommended.

3.1.3 Curtain wall cladding or 'stick systems'

Here, the cladding is self-supporting, extending over several floors of the primary structure (Figure 3.10). The vertical loads are taken at one point and the horizontal loads are distributed at each level. Unlike rainscreen cladding, this system is generally weatherproof and meets insulation requirements. The structural elements are normally formed of purpose-made aluminium sections.

Figure 3.10: Curtain wall



The vertical elements are usually referred to as 'mullions' and are continuous (though may be made of discrete 'sticks' connected together), supported by the connections to the primary structure. The horizontal elements are commonly referred to as 'transoms', and span between the mullions with load transfer shear keys at each end. The transoms support the permanent actions of the infill panels, with the horizontal loads shared between the mullions and transoms. Sometimes an intermediate floor is remote from the cladding line, for space and architectural reasons, and the mullions are required to span two or more floors.

Where this type of cladding extends to more than 4–5 levels, it is split structurally, with the permanent actions of the upper section carried separately. Effectively the

system repeats. This method accommodates differential vertical movement by having defined vertical movement joints below each vertical support bracket.

3.2 Information transfer

It is essential that from the outset of the structural design, realistic cladding loads are conveyed to the structural engineer responsible for the primary structure, and that deflection limits are established. Should the cladding designer be appointed after the structural design has commenced, it is important to establish what allowances have been made and that these are adequate.

The cladding loads may be communicated as 'area loads', 'line loads' or 'point loads' and the most appropriate form to express this will depend on the cladding type and how the loads are transferred to the primary structure (as described previously). If area/line loads have been used in the structural design, the local effects of point loads from fixings need to be accounted for.

It is possible that different cladding types will be used on the same project, so loading information should be specific to each type. Drawings that show the loading and location in a clear manner should be issued to all parties.

Wind loads (Section 2.3.2) are generally the most significant loads for cladding. While the design of the primary structure uses appropriately averaged wind loads, those for the cladding will be different, as they are more local and generally much higher near corners and at parapets. It is important to ensure that information is made available on the local wind speed, along with any directional variations and effects of local topography, so that accurate design wind loads on the cladding can be established.

While the building stability during construction may not be within the remit of the cladding designer, information on this is required to ensure that the cladding can be installed safely.

The cladding designer needs to consider the effects of high winds on partially clad structures and the resultant forces on the cladding once installed. These temporary conditions must be established and accounted for between the facade contractor and the primary structure temporary works designer.

Fixing details developed by the facade contractor should be shared with the structural engineer responsible for the primary structure. Any implications of incorporating these into the structural design must be established by the

structural engineer and the issues discussed and resolved at the design stage, prior to construction of the structural frame. Such issues are likely to include:

- Additional bending moments to columns
- Torsion into edge beams
- Site welding requirements and where this can/can't be applied to a primary steel structure and around structural connections
- Restrictions on fixing types and locations e.g. due to post- or pre-tensioned structures and their tendon positions
- Reinforcement cover requirements and positioning in relation to cladding fixing points
- Feasibility and limitations of post-drilled fixings and potential damage to reinforcement
- Any facade fixing remedial work methodologies

It is important to coordinate between the primary structure contractors and the specialist facade contractor.

Discussion between the specialist facade contractor, the structural sub-contractors and the structural engineer should include all aforementioned issues, extending into more detail on such matters as:

- Agreeing exact locations of facade fixings onto the primary structure
- Agreeing the type of fixings that will be used and which parts of these will be in the structural contractor's design and construction package, and which parts will be in the facade contractor's remit e.g. cleats welded to a steelwork structural frame to receive cladding fixings, or cast-in channels in a concrete primary frame
- Construction tolerances must be agreed, as must the positional accuracy of any elements within the structural package that will interface with the cladding
- Programming and sequencing of works must be carefully coordinated to ensure uninterrupted facade installation
- Agreement on any required pre-set in the cladding installation, should significant movement in the structure be anticipated between installation of the cladding and completion of construction

3.3 Cladding load transfer principles

When fixing to the support structure it is important to consider the relative movements between it and the cladding. Claddings units are comparatively rigid in plane. Movement in the supporting structure can involve lateral sway, vertical deflection due to permanent actions,

imposed loads and frame shrinkage. These need to be quantified and catered for in securing the cladding.

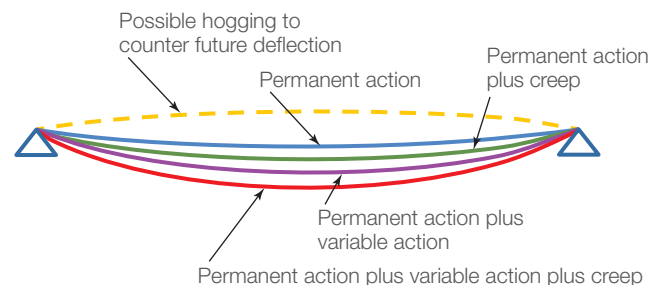
3.3.1 Vertical deflection of support structure

Panel systems and support systems that span structural bays need little consideration in terms of the local effects of deflection, however differential movement occurring between structural levels of the supporting structure do need to be taken into account. For steel frames this will be minimal, but masonry and reinforced concrete structures can have significant long-term vertical movements. These are usually catered for by ensuring that an adequate horizontal gap is established between successive units vertically. The gap should be more than the anticipated movement, as movements are calculated using approximate methods and may be exceeded.

3.3.2 Vertical deflection of slab edges

This is important where the edge of a floor at a distance from the supporting columns is used to support the cladding, and even more so where a number of cladding units are used in each bay. The deflection can compromise many factors, and these will have effect at different times in the life of the system (Figure 3.11).

Figure 3.11: Slab deflections



The slab edge deflection can involve:

- Elastic permanent action (short-term) — this usually takes effect as the cladding is installed
- Creep permanent action (long-term) — reinforced concrete slabs will have long-term creep deflection, particularly if the slab is prestressed. If the slab edge is stiffened with an edge beam this will be reduced. A steel edge beam, independent of the slab edge, will virtually eliminate this factor
- Elastic variable action (short-term) — the slab will react to the applied loads. In reality, the design variable action is very unlikely to be reached, although it is not unknown for it to be exceeded locally e.g. by a row of filing cabinets
- Creep imposed load (long-term) — this is similar to the creep permanent action, except that transient variable actions are not likely to be the cause. Again, a row of filing cabinets could well affect this