The Institution of Structural Engineers

Aspects of

Cladding

of interest to:

- Structural Engineers
- Architects
- Surveyors
- Contractors
- Building Owners
- Clients
- Local Authorities

AUGUST 1995

The Institution of Structural Engineers
11 UPPER BELGRAVE STREET, LONDON SWIX 8BH

Constitution of Task Group

David Doran*, BSc(Eng), DIC, FCGI, CEng, FIStructE, FICE *Chairman* (Consulting Civil & Structural Engineer)
H P J Taylor, BSc(Tech), PhD, FEng, FIStructE, FICE *Vice-chairman* (Costain Dowmac Ltd)
W A Black*, MSc, CEng, MIStructE, MICE, FRICS (Drivers Jonas)
D Brown[A]**,** (Sheppard Robson)
J R Campbell, BSc(Hons) ARCH DipAARIBA (Terry Farrell Partnership)
D Coates, MSc, CEng, MICE (Tarmac)
C Cockerton*, BSc(Eng), CEng, MICE, MIWES (Technotrade)
E W Dore*, CEng, FIStructE, MICE, (Consulting Civil and Structural Engineer)
G T Harding[B]**,** DIC , CEng, FIStructE, MICE (Department of the Environment)
B S Lamden, FRICS, ACIArb (Hillier Parker & Co)
J F A Moore[A]**,** BSc(Eng), MA (Cantab), DIC, PhD, CEng, MIStructE (Department of the Environment)
P A Ryan, CEng, BSc, PhD, MIStructE, MIMarE (W S Atkins Ltd)
J *G* Smith, MICE (James Consulting Engineers)
R J M Sutherland, BA, FEng, FIStructE, FICE (Harris & Sutherland)
M Wilson*, CEng, FIStructE (Michael Wilson Associates)

Corresponding members
R Blackwell, BE, CEng, MIStructE (Facet Consulting Engineers, Brisbane, Australia)
R M Kennard, BSc(Eng) PhD CEng FICE (Harris & Sutherland Hong Kong)
C A Muschenheim, (Skidmore Owings and Merrill)
F S H Ng, BSc, CEng, FIStructE, FICE (Harris & Sutherland Hong Kong)

Secretary

A K A Lorans* BSc(Eng), ACGI (The Institution of Structural Engineers)

* Indicates members of the Co-ordination/Editing Panel chaired by E W Dore.
[A] Served until February 1993
[B] Served from February 1993

Published by SETO Ltd, 11 Upper Belgrave Street, London SWlX 8BH

ISBN 1 874266 15 8

First published 1995

Cover photograph reproduced by kind permission of the Michael Barclay Partnership and Peter Bell & Partners

Contents

Foreword

The eighth report of the Standing Committee on Structural Safety (SCOSS) recommended that the professional engineering Institutions should produce a guide for the design and erection of cladding. This report is a response to that request. SCOSS and others have become increasingly concerned with the risk to the public of failure of defective cladding.

Cladding is a complex subject; it comprises perhaps a quarter of the cost of a building. It embraces many materials; its design and construction draws on many disciplines such as engineering, architecture and building physics. This was recognised by inviting professionals other than structural engineers, including overseas corresponding members, to join our Task Group. The contribution of cladding to the building envelope is significant; any shortcomings are soon apparent and costly to repair. The Task Group was dismayed to find in our study that a high percentage of cladding assemblies initially fail to pass a simple water jet test. There is therefore a pressing need to improve the approach of industry to this subject; to transfer knowledge from those who 'know' to those who 'need to know'.

The Task Group has identified many areas where a structural engineer may be involved in cladding. These include:

- design, e.g. for consultant, contractor or supplier
- construction, e.g. fabrication, erection
- inspection, e.g. as a resident engineer
- building control
- testing
- appraisal of existing cladding
- project management of the process.

This report therefore goes beyond the narrow confines of structural engineering mechanics and encourages engineers to broaden their knowledge. It is also a warning to an engineer to clarify the brief, define responsibilities and agree an appropriate fee. The Task Group are also confident that the report will be of interest to other construction professionals.

Guidance is given for the following methods of specification:

- performance
- prescriptive.

In conclusion may I thank members of the Task Group for their hard work and professionalism, Eric Dore for his patient chairmanship of the sub-committee responsible for co-ordination and editing and finally Andy Lorans for his skill in distilling many individual contributions into a coherent document.

Constructive suggestions on this report would be welcomed and should be addressed to the Institution.

David Doran
Task Group Chairman
July 1995

Acknowledgements

The Task Group would like to acknowledge the additional helpful contributions received from:

- Building Research Establishment
- Bath Centre for Window & Cladding Technology
- City University
- G. Wimpey plc
- The Michael Barclay Partnership
- Taywood Engineering Ltd
- SGS/Yarsley.

1 Glossary

Only the following descriptive terms used in the report are defined here because there is thought to be a possibility that they might otherwise be misunderstood.

Cladding
Cladding (other than roofs - a roof being considered to be any surface inclined at an angle greater than 15° from the vertical) is defined as a near vertical enclosure, facing, or architectural feature applied to and additional to any loadbearing enclosure or structural framing to a building which is not intentionally bonded to such loadbearing construction as to exert common action under load.

Cladding can also be used as soffits.

Cladding gasket
A flexible, preformed extrusion or moulding that provides a seal between part of a structure and its cladding or between adjacent cladding units.

Curtain walling
A form of cladding, commonly comprising a light metal carrier framework which supports pre-assembled opaque, translucent or transparent infill panels. The term embraces many different construction methods and materials.

Designer
The person responsible for the detailed design and specification.

Fixing
A device used to secure a fixture to a base material. In international terminology, synonyms for fixing are anchor, anchor bolt, anchoring unit or fastner.

2 Introduction and scope

2.1 Background

After the second world war a radical change took place in the construction of the external facades of buildings. Traditional heavy masonry enclosures were superseded by wall claddings of various types, including curtain walling, profile sheeting and thin masonry slabbing. In addition, new and possibly untried materials were sometimes used. These enclosures required support and restraint, usually achieved by mechanical fixings The vulnerability of such enclosures to climatic and building movements and their reliance on good workmanship became important and the learning curve on these aspects of this type of construction continues to this day.

Over the last 30 years there have been a large number of failures involving external cladding systems in their various forms. Most of these failures have initially become detectable as defects in serviceability but have sometimes resulted in dangerous situations, a few of which have unfortunately resulted in death or serious injury to members of the public.

Traditionally, and until recently in the UK, engineers were not directly involved in the cladding of buildings except to consider its secondary effect on their structural design. However, this lack of direct responsibility has not guaranteed immunity from litigation in the event of failure. With the increasing complexity of cladding systems, and the possibly serious consequences of failure, both financial and legal, it is now becoming common practice for engineers to be given the responsibility for designing cladding fixings and/or monitoring the designs of others.

Experience gained from a study of past cladding failures has indicated that a suitable degree of structural engineering input is necessary at an early stage to enhance the performance of cladding in service for several reasons, including the achievement of adequate safety.

2.2 Purpose of report

This report is intended to provide guidance to engineers and other construction professionals in respect of the complex problems which need to be addressed in assessing the structural aspects of various types of external cladding to buildings. It also sets out to provide advice on management, specifications, design and detailing for traditional, standard and bespoke systems of cladding, both new and existing, as well as the resolution of problems, repairs and renovation.

Consideration is given to a wide range of materials which include:

- masonry, e.g. brick, stone, terracotta, faience, concrete, etc.
- precast reinforced concrete
- prestressed and post tensioned concrete
- glass reinforced concrete (GRC)
- metals
- glass
- glass reinforced plastic (GRP)
- slates and tiles
- timber
- applied renderings and coatings.

Curtain walling is also dealt with covering the three principles by which the prevention of leakage may be achieved:

- the front seal principle
- the drained and ventilated principle
- the rainscreen pressure equalisation principle.

The use of these materials and systems in new build, renovation, and repair and their likely performance for appraisal purposes are considered.

The design, specification, and detailing of cladding systems, applied loadings, accommodation of movements relating to the building and the cladding, building tolerances, and the need for, and scope of, testing are discussed. Cladding suspended below horizontal or sloping soffits, or inclined more than 15° from the vertical, requires special consideration.

The need for regular inspection of all types of cladding and for carrying out any required maintenance to give continuing safety and effectiveness in service cannot be over-emphasised. The inclusion of cladding elements in a planned maintenance program for the building is strongly recommended.

Investigation and research continue into the wide and complex aspects of building cladding and a number of groups are currently engaged in relevant work. It is incumbent upon structural engineers acting within the brief to satisfy themselves regarding the structural integrity of the cladding to a building, including any units manufactured off-site. Engineers should not hesitate to seek expert advice when necessary on aspects of cladding systems with which they might not be totally familiar.

2.3 Standards and regulations

It will be necessary to comply with *The Building Regulations* which apply to the erection, repair, renewal or replacement of cladding and the local building control office should be consulted at an early stage to determine their applicability. Wide discretion is available to building control to accept new materials and innovative methods for cladding buildings. Provision is made for appeal in *The Building Act 1984* for the determination of the Secretary of State regarding disputes and questions arising between a Local Authority and an applicant.

This document must be read in conjunction with the relevant British Standards and other documents (see bibliographies, Tables 6A1-8 and 6B in Chapter 6 and Appendix B) and account must be taken of legislative requirements. Although many of the most important standard and regulatory references are given, these are not intended to be absolutely comprehensive and may change subsequent to the date of this report.

Whilst this report does not deal with internal cladding or specifically civil engineering structures, it is anticipated that many of the principles stated here will apply. This report is primarily written for non-seismic areas. Where such seismic conditions exist, compliance with local earthquake recommendations is essential.

2.4 Status of the report

The Institution of Structural Engineers has produced this report as a guide and, as such, it is only intended for use as a guide. It is not intended to provide the definitive approach in any situation, as in all circumstances the party best placed to decide on the appropriate course of action will be the structural engineer undertaking the particular project.

3 Management

3.1 Communication

The process of design and erection of cladding on a building is a team effort, more so than in some other aspects of construction. Cladding has appearance, environmental and, structural aspects, all of which have to be satisfied and reconciled in the final construction. This range of consideration requires the co-operation of the whole building team. For example, the architect would determine the appearance and be closely involved in other aspects. The structural engineer would provide data on building movement and zones for fixings. The service engineer would be closely involved in the environmental physics of the envelope etc. Further topics to be discussed by the team include buildability, delivery, agreement of use of site resources and discussions with authorities, including fire officers.

The cladding designer is required to work and communicate with this diffuse team, within the framework of the project's contractual arrangements. Clear methods of communication with a minimum of bureaucracy are a vital part of sucessful quality management.

3.2 Responsibilities

The contractual arrangement is an important aspect of management as it defines responsibility and the communication chain. Four examples of contract organisation are shown in the form of management charts, see Fig. 3.1 (a) to (d). In the traditional contract the architect and structural engineer have direct communication responsibilities with the client and main contractor as shown in Fig. 3.1 (a). The usual contractual responsibilities are also indicated.

The major roles can be summarised as follows:

S1 Carrying out structural work under Association of Consulting Engineers or similar Agreements, with no responsibility for the cladding except for the interface where the cladding is actually attached to the building.

S2 As above, but with the additional duty to carry out the design and/or specification for the cladding on cladding systems such as brickwork, concrete and glazed screens. An inspection role may be added but this must be clearly stated in the brief.

S3 Carrying out structural engineering functions as part of a specialist cladding consultancy working with the client's design team in providing cladding design drawings and technical specifications. Again, an inspection role may be required, but this must be clearly stated in the brief to avoid any confusion in responsibility between the structural engineer for the building and the cladding consultant. (This does not preclude the possibility of a structural engineer combining the functions of S1 and S3.)

S4 Carrying out structural engineering functions as part of a cladding supplier's organisation, working from cladding drawings and specifications provided by the client's design team.

S5 Carrying out structural engineering functions as part of a cladding supplier's organisation, preparing technical product specifications for trade literature, pre-tender interviews, trade exhibitions and presentations.

S6 Carrying out independent structural engineering functions or technical audits for a checking agency or client.

The separate roles of the structural engineer which have been outlined are indicative rather than definitive. It is worth noting that engineers may change their role during the course of a project.

The engineer, during the course of a contract, may change or combine any of the roles described. Whoever has the main responsibility for design may well need the advice of others in preparing the specification. In principle, any contributors to the design process should carry responsibility for their input. If, for example, the cladding designer or manufacturer changes an aspect of the architect's requirements for insulation or vapour barriers without approval and problems result, they clearly will be held responsible. If, on the other hand, the architects define the environmental conditions, insulation thickness and vapour barrier position and no changes are made, then they should assume responsibility.

Contractual arrangements where responsibility is taken by one party, often the cladding supplier, are not uncommon and have the attraction of simplicity to the specifier and main contractor. However, with such responsibility, team work and discussion is more important than ever.

3.3 Quality systems

Quality systems and job procedures are important and give a framework for the planning and assessment of all activities. Comparisons with previous jobs, not just in a facile way but in detail, allow the specifiers to assess the necessary levels of workmanship and whether they are being achieved during a contract. A quality assurance system should also allow training activities to be checked and give confidence that the operatives have been properly informed of what is required of them, and the difference between good and bad practice.

The benefits of independent inspection at all stages cannot be over-emphasised.

The aim of quality management is to prevent errors of any kind. Formal or informal quality management systems have been introduced in most organisations responsible for design, manufacture, supply and construction. Each will have established its own procedures for communication. The project team, as a combination of organisations, should endeavour to see that its members adopt complementary communication practices appropriate to the particular project. Aspects of quality management also arise in the topics covered in the following sections.

3.4 Workmanship

Good workmanship primarily results from using suitably trained staff carrying out practically planned operations in adequate surroundings. This holds true for assembly and production work in the factory and for work on site.

Good communications are essential to enable all the members of the design and construction team to be involved in the design stage. The key to good workmanship can be summarised as making sure that:

- work standards and techniques can be defined, seen, accepted or rejected
- details are such that good workmanship is possible
- staff have working conditions that allow good workmanship to be achieved
- staff have sufficient time to undertake the work properly.

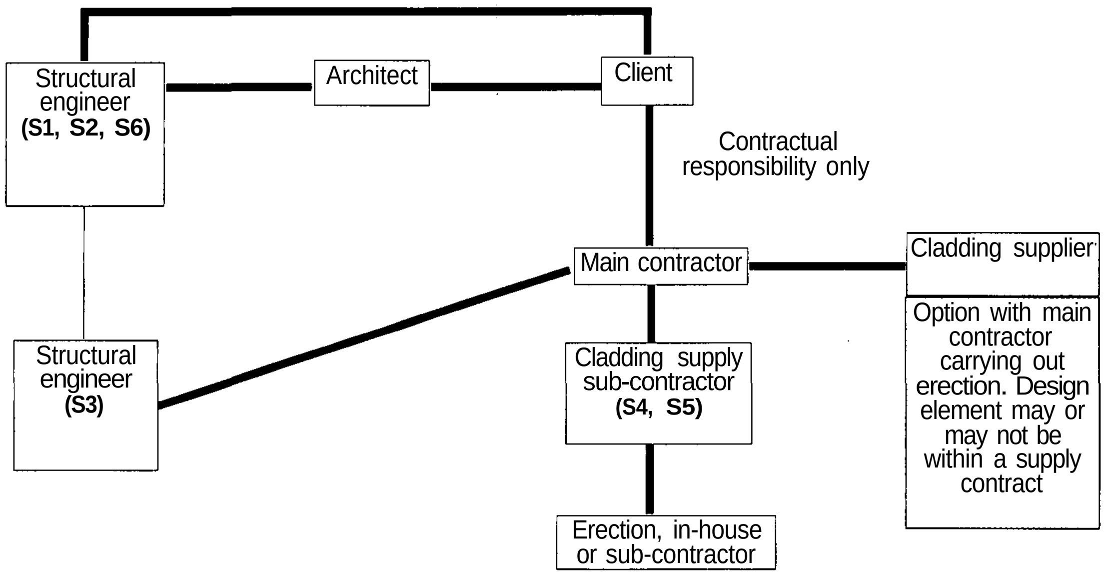


Fig. 3.1 (a) Example ofa traditional contract

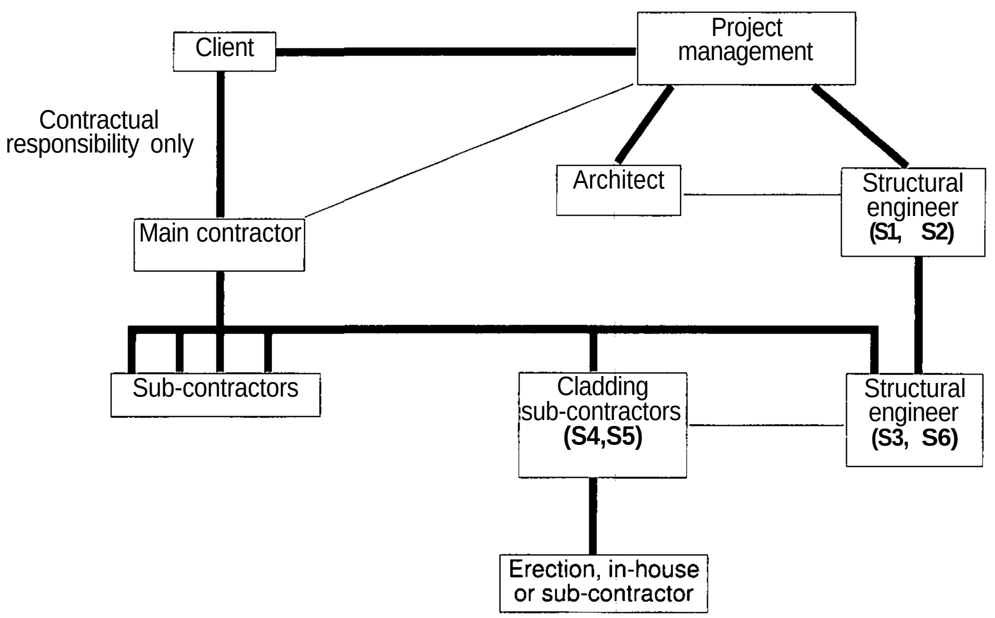


Fig. 3.1 (b) Example ofa project management contract

Fig. 3.1 Examples ofpossible contract arrangements

Table 3A Zones of responsibility for structural engineers S1-S6 (see section 3.2)

Role of structural engineer	Building	Effect of cladding on building frame	Fixings	Sub-frame (if used)	All elements of cladding	Cladding inspection
S1	ü	ü	possible	X	X	X
S2	ü	ü	ü	ü	possible	possible
S3	possible	ü	ü	X	ü	possible
S4	X	X	possible	possible	possible	possible
S5	X	X	possible	possible	possible	X
S6	checking responsibility possible in all aspects					

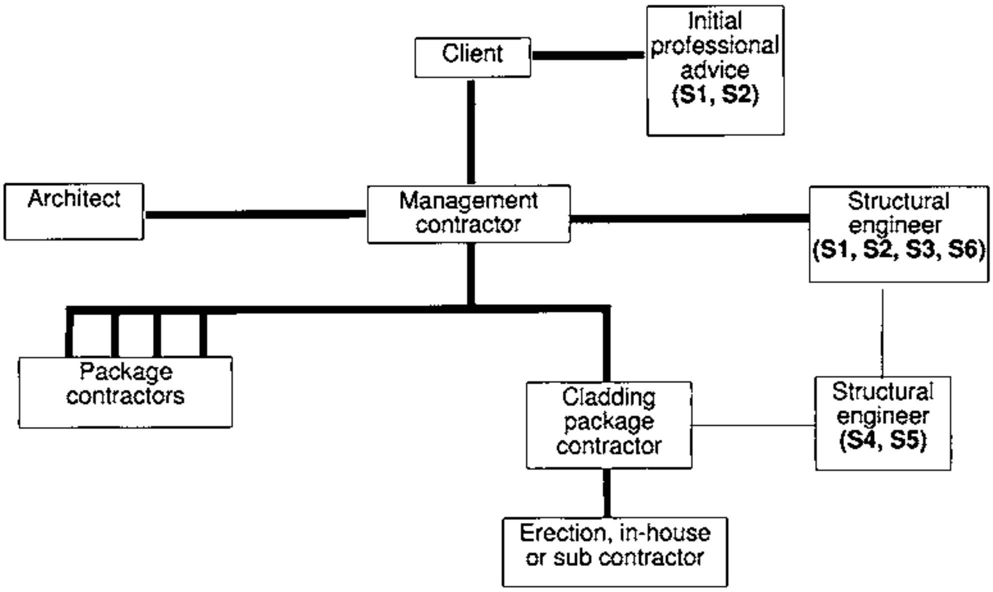


Fig. 3.1 (c) Example of a management contract

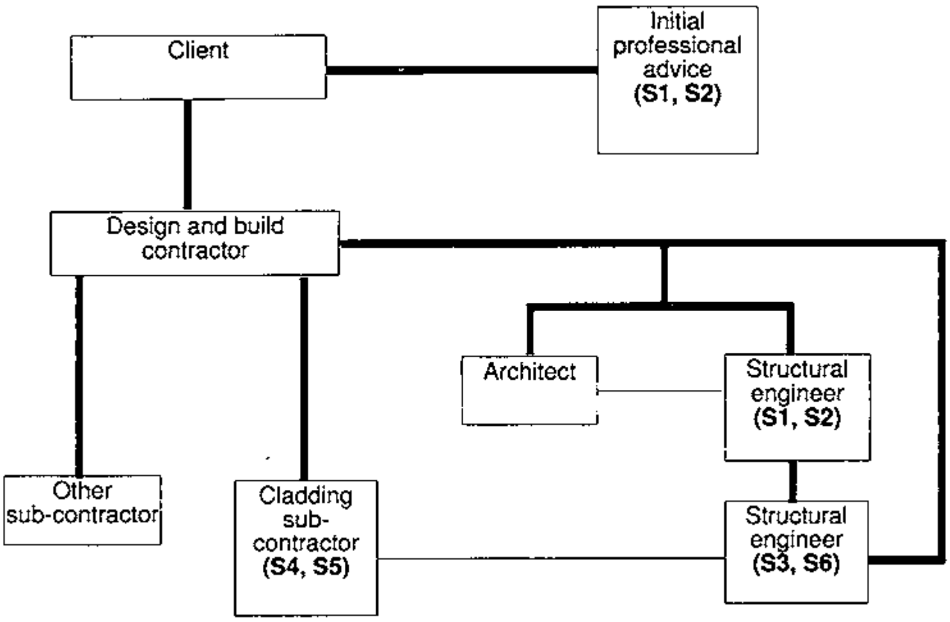


Fig. 3.1 (d) Example of a design and build contract

Fig. 3.1 *(Cont 'd) Examples ofpossible contract arrangements*

NOTES:

1. The above charts are for typical contractual arrangements drawn from a wide variety of possibilities
2. Warranties between the parties are not indicated on the above diagram but should be clarified at the outset
3. The designation Sl-S6 refers to possible destinctions in the role of the structural engineer as suggested in section 3.2.
4. Local authority approval, probably both planning and building control, is necessary in most cases of provision of cladding. Obtaining such approval is usually delegated by the client to the design team.
5. Key: ——— Information flow - necessary or possible.

━━━ Contractual responsibility, including information flow, where appropiate

3.5 Design phase

The designer should only start detailed design when a full brief has been agreed. The architect, engineer and contractors should, among other things, establish:

- design life
- loadings
- fire resistance requirements
- external and internal environmental data
- tolerances
- access and cranage limitations

On some occasions the architect and engineer are able to hand over the results of wind tunnel tests which have been carried out on a model of the structure. An important aspect of the management of the design process is to make sure that these data are assembled, checked, recorded and agreed by all parties. The cladding designer takes these data and prepares the design to comply with it.

Design is carried out in accordance with recognised Codes of Practice but, on occasion, data on the particular cladding system, which may be of a proprietary nature, may also be used. Approval of the design by all contributors and, if necessary by the client, should always be sought and given or amended by agreement as soon as possible. It should be recognised that the performance of the cladding system should then be tested, physically or theoretically, against the design and original data. The designer will also be required to meet with the site management team to confirm that the cladding system is capable of being erected safely, within tolerance, on time and within budget.

Flashing arrangements at cill, roof, openings and junctions should be given particular attention and form an integral part of the design, requiring consideration at an early stage. The configuration of flashing and closures will often dictate elements of construction sequence and delivery periods for material with special coatings may result in delay. Lack of detail and/or co-ordination during the design process can lead to ad-hoc arrangements in these areas, thereby reducing quality of performance. Frequently these details are omitted from the overall design activity and become the responsibility of the sub-contractor where they may be overlooked beyond the point at which they become critical. In practice, these comparatively small items can lead to significant performance problems, such as water penetration, which may affect insulation and the corrosion properties of support members.

3.6 Manufacture

Quality control of factory produced individual units ofa cladding system can most easily be carried out during their manufacture. An experienced manufacturer should have an organisation that is capable of designing appropriate moulds, fittings, jigs, etc. that allow the final cladding system to be prepared to the specified standards.

Often samples are prepared and approved at an early stage in the manufacturing process. It is important that these samples are seen as typical of the workmanship and representative of the average standard of finish, appearance and durability that will be achieved on site and not a minimum standard. The subsequent work should be compared with the samples taking account of the viewing distance and exposure on the building. Some contracts require the provision of mock-ups and have tests for rain penetration, etc. It is important that these tests are carred out sufficiently early for modification to be made either to the design or to the installation method if problems arise under test.

3.7 Site work

The erection of cladding systems on buildings may be carried out by site staff working for the manufacturer or by sub-contract erection specialists. In either case it is rare that resources, cranage, scaffolding, access, etc. can be given totally to the erectors. Some sharing of resources with other activities is usually required. In order to eliminate difficulties with respect to the provision of cranes, etc. at the right time, it is important that the erection contract is planned out in detail. The cladding system should also be designed to minimise hook time, for example, by having temporary support and fixing positions which can take the panel off the crane hook very quickly and from which the panel may be manoeuvred into its correct position and the final fixing system connected.

The planning of the activities in a typical day of an erection contract will require the agreement of the authorities with respect to transport and parking, probably with the assembly of trucks in some parking area near to the job site from where they can be called when the crane is available. It is an important part of the site management responsibility to plan the delivery schedule so that it is approved by the local authorities and police and that the site building programme, including availability of cranage, scaffolding, etc. is consistent with any transport restrictions.

Before work starts on site, it is important to carry out an overall survey of the 'as built' structure in order that exterior cladding planes can be established. This is often a contractual requirement, but this may be difficult if the structure is only partially complete when cladding erection commences. Where the programme dictates that cladding erection commences before frame completion, it is even more essential that the contractor maintain the frame within agreed tolerances. This can be achieved by accurate floor-by-floor monitoring of the structure's position, and appropriate correction. Should any tolerance be exceeded, one of the following measures should be taken:

- re-design of fixings
- adjustment or partial reconstruction of the frame.

This is yet another example where flexibility is required of the project team.

It is inevitable that, from time to time, some site modification will be required of fixing and other details. It is advisable, as soon as the initial survey has been carried out, for typical modifications to be projected, drawn out and agreed. Ideally, therefore, the cladding design should allow for contingency solutions.

It is often necessary to erect panels onto a facade of a building which is scaffolded and where this scaffold is used by builders or by labour higher up the building. Scaffolding should be designed to allow for such erection. Proposals to modify scaffold to allow space for the cladding element to be lowered down to the fixing position have to be thought out carefully. Authorisation of modification should be agreed by the responsible authority and the modified and subsequent reinstated scaffold should also be checked by that authority. Unauthorised modification of scaffold should be strictly forbidden.

The inspection and protection from damage of finished work is often the responsibility of the cladding supplier. This can present difficulties if there is an extended period of time after the structure has been clad and before all building work ceases. Co-operation is required so that access to the external envelope of the structure is controlled so that following trades do not damage the finished work.

In all these areas ofmanagement, a quality assurance approach is of great value, not just because it leads to better quality control but because it clarifies and underlines contract responsibilities.

3.8 Inspection

Regardless of the competency of the chosen cladding system, poor workmanship in a very small proportion of the overall clad area can defeat this purpose. The standard of work achieved therefore needs to be assured both during manufacture and on site in the erection phase. The inspection process should be defined within this context.

The required standards of work should be established by reference to the specification and a suitable system of checks and records instituted involving the contractor, the manufacturer and the cladding sub-contractor. Clear instructions for performing the work should be given to those doing the work in order to achieve the required end product.

Workmanship considerations on site are particularly important at junctions between cladding panels and where dissimilar materials are used, as well as the specified torqued tightness of bolted fixings and the application of sealing material. Some cladding systems are vulnerable to cosmetic damage and so workmanship should extend to protection of finished work, especially at lower levels.

3.9 Safety

Cladding work, like all construction, requires compliance with all relevant Health and Safety legislation. Safe methods of working shou1d be documented and agreed between the contractor and the cladding sub-contractor.

Where c1adding panels are lifted and temporari1y located on loading platforms, these platforms should be subject to temporary works design considerations. Access platforms should not be used as storage platforms.

A particular problem with the erection of cladding is the need for men to work on a floor outside the normal barrier. A solution to this problem is to move the barrier on the building edge back into the Structure to create sufficient space for Safe working outside it, typically lm. Men working in this edge zone must on all occasions be secured by harness.

Scaffolding should be positioned at a suitable distance from the fixing line so as to allow adequate working space. Consideration should also be given to providing a means of preventing items such as loose bolts and brackets from falling to lower levels. The scaffold must be fitted with an inner guard rail if men are able to fall more than 2m down the gap between the scaffold and the building. Scaffolding should not be dismantled Until the work is complete and Satisfactory inspected. This removes the risks associated with resorting to unorthodox means of access to carry out remedia1 work The remova1 of temporary members tying scaffold to the building or structure must be given particular attention and additional substitute bracing provided where necessary to compensate.

Where elevating platforms are used, these should be located on prepared areas and loaded in accordance with the manufacturers' requirements. Operators should be trained in their use. Unauthorised modifications to passenger hoists should be prohibited. Chain blocks may be used but attention should be paid to their safe fixing to the structure and to checking that the blocks and supporting structure are not overloaded. Chain blocks with baskets to retain paid out chain should be used. Oily chain can create slippery surfaces and also disfigure cladding if contact is made. Gin wheels should not be used.

3-10 References and bibliography

Note: See Appendix B for a listing of full titles of British and European Standards referenced in the text. Some other relevant standardsare also listed.

Chartered Institute of Building. *Code of Practicefor project management for construction and development.* Ascot: CIOB, 1992.

BS 8000 *Workmanship on buildingsites.* London: BSI, 1989-.

TampereUniversityofTechnology,Finland;CIRIA. *The UKconstruction industry: a continentalview.* London: 1992. (CIRIA SP82.)

Institution of Structural Engineers. *Guide to good management practice for engineerjng design office.* London: IStruct E, 1991.

BS EN IS0 9000: *Quality management and quality assurance standards.* London:BSI, 1994-

Construction (Design andManagement)Regulations 1994. SI 1994, No. 3140.London:HMSO, 1995.

Healthandsafetyatwork,etc. Act 1974. London: HMSO, 1975.

ACE. *Conditions of engagement.* London: Association of Consulting Engineers

Agreement 1: *for report and advisory work.* 1990

Agreement 2: *for civil, mechanical and electrical work andfor structural engineering work where an architect is appointed by the client.* 1993.

Agreement 3: *for structural engineering work where an architect is appointed by the client.* 1990

Agreement 3 (1 984): *for structural engineering work where an architect is appointed by the client - harmonised with the 'Architects appointment* 1990

Agreement 4A (i) *full duties: for engineering services in relation to sub-contract works.* 1990

Agreement 4B (198 1): *for engineerjng services in relation to direct contract works.* 1991

Agreement 4A (iii) *(198l)* performance *duties: engineering services in relation to sub-contract Works.* 1990

Agreement 4A (ii) (1 981) *abridged duties: for engineering services in relation to sub-contract works.* 1990

4 Specifications

4.1 Introduction

4.1.1 General

In structural engineering terms, cladding systems fall into two well defined categories:

- those which are designed by the client's design team and can be considered as non-proprietary solutions
- those designed by cladding specialists.

The client's design team may, for instance, be responsible for precast concrete cladding. Specialists or suppliers may need to be consulted when considering proprietary systems.

The role of the structural engineer in this wide range of contexts is defined into six categories in section 3.2 and these are referred to as S1, S2, etc. below.

Whilst in general working to British Standards, specifiers should be aware of the requirements of the Construction Products Directive and CEN documents.

4.1.2 Prescriptive materials and workmanship specifications

Specifications are often referred to as prescriptive or performance based. The traditional specification for materials and workmanship is of the prescriptive type. When adopting the prescriptive route, the client's design team prepares drawings of all the relevant details, interfaces, drainage details, anchorages, etc. having taken account of all the performance requirements. The specification describes the materials to be used and the manner in which they are to be installed.

While it is of interest to the builder/contractor to know what the internal climate of the building will be and what wind loads the wall has been designed for, this information is not necessary to actually build the cladding. Where the structural engineer (S1) has no responsibility for the cladding, the rest of the client's design team prepares the entire cladding specification. The structural engineer (S1) should nevertheless provide:

- assumed cladding self-weight
- assumed imposed loads from the cladding to the frame
- details of acceptable attachment to main frame
- details of tolerances

to the team as part of the client's cladding specification.

Where the structural engineer (S2) has additional duties, this will entail the preparation of the appropriate particular specification. This may also include the production of some drawings. This may be included as part of the structural engineering specification, or it may be passed on to the design team together with appropriately designed fixing details, main frame movements and tolerances to be included in the overall cladding specification.

4.1.3 Performance specifications

A different approach is required when preparing specifications for cladding to be designed by someone other that the client's design team. It is sensible to allow the specialist contractor/supplier freedom to use experience and special knowledge to exploit the best features of any proprietary systems, materials and products. Accordingly, detailed information about the building and the relevant ambient conditions is required. When the design team is required to assess tendered proposals, it is convenient to standardise the salient design criteria, the design methods and procedures.

The usual way of standardising relevant criteria and methods is to prepare performance specifications. In reality, performance specifications do include prescriptive requirements for particular elements or parts of elements such as colour, glass, framing materials and fixings, etc. which would be in a traditional materials and workmanship specification.

A performance specification should therefore be seen as a combination of performance related requirements and prescriptive detail. The balance between the two will vary from building to building depending on how many details can be fixed in advance of tendering, but it is important to recognise the essential difference between them and to separate them in the specificationdocument.

An important consequence of specifying by performance is the need to determine the degree of compliance of the tendered proposals. For some requirements, methods of calculation and analytical procedures are sufficiently developed to allow reliable appraisal by the design team. Structural integrity deflection criteria, conservation of internal heat, exclusion of solar radiation and sound attenuation usually fall into this group. Other requirements, such as weather tightness, are difficult to appraise without recourse to testing, so the performance specification should describe the methods, procedures and testing regimes to be used and incorporated in the tender required from the specialist cladding contractor.

Proper maintenance is important to the long-term performance of the cladding, and this aspect should be included in the tender appraisal. What is appropriate will vary in frequency, extent and complexity from one system to another, and therefore the specification must ask the tenderer to provide details of cleaning, repairs and replacements needed during the design life of the cladding.

When working for a cladding supplier, it will be the task of the structural engineer (S4) to prepare drawings, calculations and specifications to meet the structural requirements of the tender. Generally, the design team prepares the performance specification. The input of the structural engineer (S1) is limited to supplying details of the loadings, particularly wind load, acceptable attachment points, main frame movements and tolerances.

A growing trend however, is for the design team leader or client to employ a specialist cladding consultant. In this case, the cladding consultant prepares the performance specification with input from the design team leader on aesthetic matters such as colour, texture, etc. The structural engineer (S3) working for the cladding consultant will provide similar input to that required when a client's design team is preparing the specification.

4.1.4 The future

It is very probable that, in the near future, specialist cladding consultants will be able to offer a full design service to clients for what up to now have been classed as proprietary cladding systems. When this happens, the cladding consultant will prepare prescriptive specifications and the cladding consultant's structural engineer (S3) will therefore prepare prescriptive specifications for any elements designed for inclusion in the cladding specification.

However, a word of warning is added here. It is not always clear where the responsibility of the cladding consultant's structural engineer (S3) ends and those of the structural engineer for the building (S1, S2) begin. This can lead to assumptions being made about their respective briefs resulting in both underestimating the extent of their respective responsibilities. In particular, responsibility for the design and inspection of primary cladding attachments to the building structure must be clearly defined.

4.2 Scope

The introduction to this Chapter has identified two distinct types of cladding specification, namely prescriptive of materials and workmanship, and performance. Section 3.2 identified a number of major possible roles for the structural engineer working in relation to a cladding contract.

The following sections relate to the form and sequence for the preparation of a performance specification, noting the issues where the structural engineer can have significant input and responsibility depending on the role being undertaken. Where appropriate, reference is also made to prescriptive specifications, again noting the role and responsibility of the structural engineer.

When carrying out technical audits, the structural engineer should obviously be aware of the requirements of the specification, but will not have any role to play in the preparation of the specification itself. For this reason, there is no further mention in this Chapter of the structural engineer (S6) acting as a technical auditor.

4.3 Form and sequence for a performance specification

The form and sequence for a performance specification can be developed by following the paragraph titles as given in sections 4.3.1 through 4.3.12.

4.3.1 The building and its environment

The specification should include, inter alia, the following clauses describing the building:

(a) role and function, including loadings, as relevant to the cladding
(b) appearance
(c) form and size
(d) relationship to its neighbours, including present and future. In particular, the orientation of facades needs to be checked to avoid dazzling occupants of adjacent buildings or road users
(e) internal climate, standard of comfort, working conditions, requirements for external noise reduction, reduction of glare and direct sunlight and minimising draughts
(f) external climate and atmospheric conditions
(g) fire requirements.

The client's design team structural engineer (S1, S2) will have used the above information to start designing the building frame. It is essential that the data used by the design team structural engineer (S1, S2) and the cladding consultant or supplier's structural engineer (S3 - S5) are compatible. The structural engineers (S1 - S5) may all have significant input to this work.

The following three issues should be agreed and confirmed by all parties:

- Items (a) to (d) inclusive allow the wind loads acting on the cladding to be assessed using current codes and standards or by wind tunnel testing. It is essential that all parties have agreed the design wind loads for all parts of the cladding before any contract for cladding is signed
- Item (e) will have been used by the architect to develop the appearance of the facade. This will provide basic information on materials, special features, e.g. atria, areas of glass, openings, etc. The design team structural engineer (Sl) will use this information for preliminary building frame and foundation design. Acceptance of loadings must be confirmed in due course by the cladding supplier structural engineer (S4, S5)
- Item (f) will establish the basic temperatures and moisture conditions that should be allowed for in the design of the building frame and the cladding. Again, relative movements between cladding and building frame must be compatible
- The design team structural engineer (S1, S2 and possibly S3) and the cladding supplier's structural engineer (S4, S5) could have significant input into item (g).

4.3.2 Description of the cladding

The description of the cladding should, amongst other items, include the following:

(a) extent and geometry
(b) attachment to the building
(c) sunscreens, walkways and access facilities
(d) fireresistance
(e) safety for the public, in particular the need for the low risk of injury from falling pieces
(f) durability and required life expectancy
(g) maintenance needs, including preparation of a manual
(h) the possibility of replacement
(i) weathertightness and the principles of its design
(j) role in the lightning protection of the building
(k) intended solidity, lightness, texture, contrasts and colours
(l) functions with other parts of the building
(m) insulation.

Whether working in the design team or with a cladding consultant, the structural engineer will have significant input into most of the items above. It is vitally important that any restrictions on the location of load carrying attachments supporting cladding should be clearly identified in the specification, e.g.:

- where structural steel edge beams lack sufficient stiffness to resist wind loads on bottom flanges
- where slab edges would deflect unduly if loaded cladding mullions are attached within the span.

The structural engineer needs to be advised of the weight of the equipment for cleaning, replacement and maintenance of external facades. If major plant is required for maintenance, then its location and operation should be identified very early in the design process.

The structural engineer should be asked to provide information regarding the durability of fixings and attachments. The materials used for fixings and attachments should be of appropriate durability. For example, where resin anchors are used or where fatigue failure may need to be considered, special specification clauses, prepared by the structural engineer, will be required.

The design team generally and a specialist cladding consultant's structural engineer (S3) will normally be involved to some extent in the specification of the other items listed.

A structural engineer (S4, S5) working for a cladding supplier will need to be aware of all the specified requirements for all the elements of the cladding and attachments before checking that they are fulfilled. The structural engineer (S4 - S5) should also check that the components of cladding are structurally adequate.

4.3.3 Technical procedures

Whether specifications are being prepared for procuring cladding, or as trade literature for marketing a cladding product, it is important that documents such as standards, codes, guides, manuals, digests and other publications need to be defined for items such as:

- loads (See Chapter 5)
- analysis and design of cladding and its supporting structure (see Chapter 7)
- dimensional deviations, tolerances and movements (see Chapters 3 and 7)
- temperature variations, solar gain, u-values and thermal properties
- acoustics
- fire resistance
- weathertightness.

In preparing performance specifications, the design team structural engineer (S1, S2) may not necessarily get involved with the specification for technical procedures. This may be done by others in the design team or the cladding consultant. However, the structural engineer should be aware of what is being included in the specification relating to the brief for the following reasons:

- The design team structural engineer (S1, S2) will have a view on the wind loads that can be safely applied to the structural frame and in some cases precisely where these loads can be applied. It will need to be confirmed that the structural engineer (S3 - S5) for the cladding consultant and cladding supplier will be using the same basic data and procedures, and understands the requirements of the design team structural engineer (S1, S2)
- The design team structural engineer (S1, S2) knows better than any member of the design team what the building movements are likely to be. The specification should generally include the documentary basis for estimating movements, and the structural engineer (S3 -S5) for the cladding consultant and cladding supplier should not be in any doubt as to what the documentation means with respect to the cladding design. For example the design team structural engineer (S1, S2) could prepare a set of sketches or drawings describing the anticipated movements of the structural frame
- Lack of understanding of building tolerances is a major source of conflict on building sites. Tolerances on building frames are considerably larger than tolerances on cladding elements. The design team structural engineer (S 1 or S2) should be aware of the documentation that will be used to assess allowable tolerances and the cladding consultant and cladding supplier should not be in any doubt as to what the documentation means with respect to the cladding. For example, the design team structural engineer (S1, S2) could prepare a set of sketches or drawings describing the anticipated tolerance envelopes for slab edges, columns and beams, etc.

It is essential that all parties involved at the interface between the cladding and the structural frame are clear on the amount of adjustment that needs to be designed into fixings to allow the cladding to be safely attached to the main frame. In addition, cladding is erected to floor datum, not a dimension above an actual floor slab level. If the floor slab level is too high the flooring above may not fit below the cladding; if it is too low the services and ceiling below may not fit.

For prescriptive specifications, some of the technical procedures will be provided by the design team structural engineer with the balance being provided by the design team leader or the cladding consultant.

Where prescriptive specifications are used, the technical procedures described will have been used by the design team leader or the cladding consultant, assisted where appropriate by their respective structural engineers (S1 - S5), to prepare the necessary information.

4.3.4 The role of the cladding supplier

In cases where the performance specification is being prepared for the procurement of cladding, the role of the cladding supplier must be defined. The structural engineer, whether working as part of the design team or with the cladding consultant, may not be involved in this definition unless playing a leading role. The following check list outlines items for definition.

The cladding supplier should:

- design to satisfy the performance requirements while incorporating the prescriptive requirements
- be responsible for satisfying the performance requirements and demonstrate compliance
- consult with local building and fire officers
- satisfy Building Regulations
- supervise installation using trained installers
- observe Health and Safety at Work Legislation
- liaise with contractors responsible for adjoining work
- take site measurements
- indicate any work which needs to be done to facilitate their own operations
- develop a programme for design, testing, fabrication and installation which is compatible with the overall building programme.

The structural engineer (S3 - S5) working for the cladding supplier should be aware of these requirements so that the structural elements of the cladding are designed to meet the specification. Any technical information for the product being marketed by the supplier should be checked by the structural engineer (S3 - S5) to confirm that it addresses the appropriate structural issues.

For prescriptive specifications, the checklist above will be described either in the specification itself or in the contract preliminaries.

4.3.5 Technical criteria

To confom with the client's design brief for the building, the design team will provide technical criteria by calculation or other methods in accordance with section 4.3.3. These include:

(a) detailed definition of the internal climate

(b) detailed definition of the external climate

(c) design values of external surface temperatures

(d) design values of wind loading and other incidental loads

(e) movement of building structure under dead loads, vertical live loads, wind, settlement, shrinkage and creep, etc.

(f) allowable tolerances in the structural frame.

For a performance specification, the structural engineer (Sl, S2 or S3), whether working as part of the design team or with a cladding consultant, will provide specification clauses for items (d) (e) and (f). The structural engineer (S4, S5) working for the supplier will use these values in the design of the cladding.

Design values for wind load are sometimes provided by the design team structural engineer (Sl, S2), the cladding consultant's structural engineer (S3) or by the cladding supplier's structural engineer (S4, S5). Whoever supplies the design values for wind load derived from codes or tests should, at an early stage, allow the other party to comment on them before a contract is signed. BS 8200 gives a useful check list of incidental loads and deflection criteria that may also have to be considered.

In carrying out an initial assessment of cladding suppliers that might be suitable for a project, the design team could ask suppliers for the performance specification relevant to the cladding system proposed.

For prescriptive specifications, the design team structural engineer (S 1, S2) or the cladding consultant's structural engineer (S3) contribute to the design and specification in accordance with previously established technical criteria.

4.3.6 Performance criteria

If the client's design team, as opposed to a supplier's design team, have designed the cladding, all the performance criteria should have been considered and the final design checked for likely compliance with the required performance during the design process and prior to the materials and workmanship specification being written. Testing and inspection of the quality of installation may be required and, if so, should be included in the specification. This aspect will require the preparation of a prescriptive specification rather than a performance specification. The design team structural engineer (SI, S2 and possibly S3) provides specification clauses where appropriate.

Where the system is designed by a cladding supplier, the design team structural engineer (Sl, S2) normally has very little responsibility for preparing information on performance but should previously have provided all the necessary data in sections 4.3.3 and 4.3.5. Performance criteria are specified by the design team or the cladding consultant.

The following is a lis tof the norma1 performance criteria that a cladding system has to satisfy:

- requirements to form an appropriate barrier
- durability, i.e. resistance to bimetallic and atmospheric corrosion, weathering, chemical attack, solar degradation, biological degradation, frost degradation, water absorption, colour retention, staining, etc.
- strength under self-weight, wind loading, impact and other incidental loading under serviceability and safety conditions
- weathertightness as defined by air permeability, watertightness and wind resistance
- thermal insulation for the wall as a whole, and separately for the framework, the glazing and the opaque panels
- condensation restrictions
- vapour barriers
- acoustic insulation for the wall as a whole and for the glazing
- movements - their magnitude and how accommodated
- fire resistance, combustibility and flame spread
- shading by glazing and or blinds and sunscreens
- safety of glass from thermal shock and impact
- compatibility of components in the wall
- compatibility of the Wall with the remainder of the building
- maintenance requirements
- design life.

The structural engineer (S4, S5) working for the cladding supplier will be designing the cladding framework to meet the performance requirements specified and will also be involved with analysing and specifying the structural performance of products being marketed by the supplier.

4.3.7 Prescriptive requirements

As stated earlier, all performance specifications for cladding will have some prescriptive sections. Requirements in terms of materials and workmanship for some or all of the following items (a) - (1) will need to be defined. Generally, the design team structural engineer (S 1, S2) will only be asked to provide input into drafting specification clauses for item (g) in the following list. Others in the design team or cladding consultant should specify the rest.

Specifications will generally consider:

(a) framework of the cladding
(b) glass
(c) opaque panelling, e.g. metal, stone, GRP, GRC, etc.
(d) insulation
(e) finishes
(f) fixings within the cladding system
(g) attachment to the building
(h) prevention of corrosion
(i) gaskets
(i) membranes
(k) sealants
(1) fireprotection.

This list may not be exhaustive.

4.3.8 Testing

As stated in the introduction, testing and the possible need for the employment of independent testing specialists is required for materials and/or assemblies where methods of calculation and analytical procedures are not sufficiently developed to determine compliance with performance requirements. Depending on the circumstances, tests may be necessary in relation to:

- structural performance, e.g. robustness, stiffness, vibration, seismic, fatigue, deformation, impact resistance, thermal movement, adhesion to substrate, etc.
- weathertightness, including air permeability, rain penetration, etc.
- buildability
- appearance factors, e.g. colour retention, reflectance, abrasion resistance, water staining, etc.
- acoustic attenuation
- thermal insulation
- safety of glass
- shading of glass
- thermal shock of glass
- condensation
- fire resistance, combustibility and flame spread
- performance of cladding after installation.

The specification should make allowance for the provision and description of specimens.

For performance specifications, the design team structural engineer (Sl, S2) will not generally be asked for input into specification clauses for testing cladding systems. This is normally done by the design team or cladding consultant. The cladding consultant's structural engineer (S3) will provide input into the drafting of specification clauses for testing cladding. However, as noted earlier, the responsibility for the design and inspection of anchorages to the building frame can be either with the cladding consultant or the design team structural engineer (SI, S2). Whoever is responsible should provide input into clauses for testing the structural integrity of anchorages to the building frame.

Where the cladding has been designed by the client's design team, compliance with performance requirements will have been established during the design process. However, testing of full scale prototypes may still be required to check watertightness. Site testing may also be specified in order to check the quality of installed work.

A structural engineer (S4, S5) working for a cladding supplier would be involved in the specification, testing and verification of the structural aspects of the products being marketed by the supplier.

4.3.9 Maintenance and operating procedure

The performance of cladding depends on proper maintmance. A performance specification should include clauses asking the cladding specialist to provide details of how the cladding system should be cleaned and how and when repairs and replacements should be carried out. The design team structural engineer (S1, S2) or the cladding consultant's structural engineer (S3) needs to be involved where maintenance equipment couldcause impact loading on cladding units.

Again, where the cladding has been designed by the client's design team, the issues of cleaning, repairs and replacement should have been considered and included in the prescriptive specification.

The structural engineer (S4, S5) working for the supplier might be involved in one or two of the items listed below. The following is a minimum list of items that should be included in a performance specification:

- requirements to achieve the specified performance for the whole of the design life
- access for, and frequency of inspection, maintenance, cleaning and replacement
- cleaning materials and other consumables
- maintenance manual with as-built drawings, illustrations and text suitable for use by the building owner
- documents confirming compliance with Health and Safety at Work and other legislation.

4.3.10 Information with tender

The major problem with performance specifications is assessing the merits of the tenders submitted. In order to make the task easier and fairer, the specification should define clearly the information that is to be submitted with the tender in terms of scope and detail. The design team structural engineer (S1, S2) or the cladding consultant's structural engineer (S3) would normally assist in preparing this part of the performance specification, e.g. a request for simple calculations confirming that deflection criteria on main frame members have been met.

A tender list of suitable specialist suppliers should have been drawn up and checked by the design team or cladding consultant while the specification was being prepared in order to eliminate irresponsible tenders. As a minimum, the following should be submitted with any tender:

- sufficient information to demonstrate that the cladding will be designed and erected satisfactorily
- a general arrangement of the system, showing geometry and form
- typical details of elements
- provisions to accommodate variations in geometry and dimensions of building structure and the cladding itself
- provisions to accommodate movements of the building structure and of the cladding relative to the structure, and of individual parts of the cladding relative to one another
- the material composition of all elements
- brand name, manufacturer's name, technical details and source of all proprietary materials
- a statemen on the durability of the elements in the cladding
- maintenance requirements of each element during its design life
- qualifications and experience of design staff and installation staff
- an outline method statement and programme on how the design will be developed, including the type and number of drawings to be produced, calculations and testing, etc.
- an outline method statement on the erection.

Where the cladding has been designed and prescribed by the client's design team, some items listed above may still be required when tenders are submitted, e.g. qualifications of installation staff. Some of these requirements may be included in contract preliminaries, rather than in the materials and workmanship specification. Again, the design team structural engineer (S1, S2) or the cladding consultant's structural engineer (S3) should have provided input into the list.

The structural engineer (S4, S5) should have a significant role to play in preparing some of the information requested by the clients design team when working for the cladding supplier.

4.311 Administration

Procedures should be clearly specified in order to administer the specialist sub-contract. The majority of the items listed below will need to be specified:

- tenderers to attend post-tender, precontract interviews
- tenderers to be ready to supply supplementary information at interview
- after appointment, to develop design in association with the design team
- submit scheme design proposals including drawings for inspection by the design team
- proposals should be agreed by the design team
- make specimens for testing
- notify the design team leader of testing dates and arrangements in sufficient time for them to make arrangements to attend if necessary
- test results should be reviewed by the design team before the cladding is finally approved
- submit all final design drawings (not shop drawings) for inspection by the design team
- all final design drawings should be endorsed by the design team before they are implemented
- prepare sets of record as-built drawings

Where the cladding has been designed by the client,s design team or the cladding consultant, the structural engineer (Sl - S3) should have a significant input into the specification clauses required. The structural engineer (S4, S5), if working for the cladding supplier, should have significant input into the administration procedures submitted.

4.3.12 Appendices to specifications

These will normally consist of extracts from other specifications, e.g. structural steelwork or structural concrete, giving details of the allowable tolerances, materials, etc. that are needed by the cladding supplier in order to comply with the performance requirements. The design team structural engineer (S1, S2) and cladding consultant's structural engineer (S3) should provide all the appendices appropriate to their work.

4.4 References and bibliography

Note: See Appendix B for a listing of full titles of British and European Standards referenced in the text. Some other relevant standards are also listed.

BS 7373 *Guide to the preparation of specifcations.* London: BSI, 1991

Willis, C. and Willis, J.: *Specification writingfor architects and surveyors.* 10th edition. Oxford: BSP, 1991

Guidance on tendersfor civil engineering contracts. London: Thomas Telford, 1983

Centre for Window and Cladding Technology. *Standard and guide to good practice for curtain walling.* Bath: Centre for Window and Cladding Technology, 1993.

Statutory Instrument 199 1 No.2768: *Building and Buildings: The Building Regulations 1991.* London: HMSO, 1991.

Dept ofthe Environment; Welsh Office. *The BuildingRegulations 1991.* London: HMSO, 1991. (Set of 14 approved documents current from 1.6.92, plus amendments.)

BS 8200 *Code of practice for design of non-loadbearing external vertical enclosures ofbuildings.* London: BSI, 1985

CP 3 Chapter V: part 2: 1972: *Wind loads.* London: BSI, 1972

Cook, N. J. : *The designer's guide to wind loading of building structures: Part 1: backgound, damage survey, wind data and structural classification.* London: Butterworth, 1985.

Cook, N. J.: *The designer's guide to windloading of building structures: part 2: static structures.* Watford; London: BRE; Butterworths, 1990

Alexander, S.J. and Lawson, *R.M.:Designfor movement in buildings,* London: CIRIA, 1981 (CIRIA Technical Note 107)

BS 6954: *Tolerancesfor buildings.* London: BSI, 1988 -

5 Loadings

5.1 Introduction

In order to avoid unintentional loading on the cladding, liaison with the designer ofthe main structure is essential. Some types of non-structural cladding, for example, that made of precast concrete, have been shown to contribute measurably to the lateral resistance of structures even though it has not been specifically designed to perform thus. By doing so, the cladding panels must attract loads which can be very significant.

The cladding, including its fixings and any furniture, should be capable of resisting and safely transmitting to its points of support all static and dynamic loads considered relevant by the design engineer (S1-S5). Codified loads may need to be enhanced for the particular situation. Eccentricities will also need to be considered, Particularly With regard to the fixings.

Significant deflection of individual cladding units or of the entire system can occur under the loads described be1ow and guidance is given in Chapter 7 ofthis report. Large deflections will lead to problems with finishes and joints, and could lead to loads being transferred across movement joints.

This Chapter discusses the main loadings that need to be considered and a number ofreferences are given, relevant mainly for the United Kingdom. The reader should refer to the appropriate codes, building regulations and standards for the particular country concerned. Loads are not given in order of importance because their significance will vary with factors such as the location and function ofthe structure.

5.2 Self-weight

Each unit has to support its own weight and may additionally have to transmit this and the weight of other units or elements, e.g. windows, to the structure.

5.3 Loading due to environmental factors

5.3.1 Wind

The wind loading on the cladding and its fixings should be based on the wind criteria used to design the main structure. However, in determining the appropriate loads, the size of the cladding units will need to be taken into account. General guidance on wind loads on cladding is given in codes of practice and in building regulations.

Additionally, account may need to be taken of the possibility of higher wind speeds occurring in narrow gaps between buildings, and of strong winds at the top of the structure being deflected downwards and affecting units at the bottom. A similar effect may be caused by taller neighbouring buildings in exceptional circumstances, in which case their proximity may have to be taken into account in assessing the wind load on the cladding units.

For a given wind direction, the pressure distribution varies around a building and even across a face. Thus, some cladding units may be in areas where high local pressures and or suctions occur for given wind directions. Pressure coefficient data identify the most vulnerable areas. For buildings with non-rectangular plan shapes and inset storeys, coefficients may vary.

In the case ofpermeable cladding systems, such as rainscreen cladding and many of those used for over-cladding, significant suction forces may occur in the cavity between them and the building at the same time as peak positive pressures occur on their windward face. Furthermore, rainscreen cladding in general only prevents a proportion of the wind load from acting on the wall behind.

5.3.2 Snow

Snow may lie on surfaces as a uniform layer or it may be blown into drifts by the wind. Cases where snow can drift, for example against a parapet or on a roof abutting a taller part of the building, should be considered. Drifted snow could particularly be a problem for light-weight cladding where the weight of the snow may be significantly higher than either the self-weight of the cladding or the wind loading that may act on it.

5.3.3 Ice

Depending on the type of cladding and the general location and exposure of the structure, ice build-up may occur in freezing weather. Icing up of cladding may be particularly significant in the case of otherwise lightweight systems as the combined weight ofthe ice and cladding may be several times that of the cladding alone.

5.4 Loads imposed by people/vehicles

5.4.1 occupants/crowds

The cladding units and their fixings should be able to resist safely horizontal loads imposed on them from use ofthe structure, e.g. from occupants leaning out of windows. In certain circumstances, e.g. grandstands, the cladding may form part of a barrer against crowd loads.

5.4.2 Access

The faces of the cladding will need to be cleaned and inspected throughout its life. This may be carried out using access cradles which are likely to come into contact with the cladding. A person on a ladder leaning against the cladding will exert a significant horizontal load. Cornice and other projecting cladding should be designed to allow for applied vertical loading.

In general, it is necessary to check the cladding specification for any requirements regarding access, e.g. there may be a need for scaffold ties or window cleaning safety line anchors.

5.4.3 Impact

The vulnerability of a cladding surface to impact depends on its location both on an individual building and the location of the building itself. Larger and more frequent impact will tend to occur on vertical surfaces adjacent to public areas rather than private ones.

Protection measures for vulnerable areas may need to be considered. In the case of lightweight cladding systems, impact loads will be particularly significant in the design ofconnections and fixings.

5.5 Loads fixed to the cladding

5.5.1 External surface loads

These must be safely transmitted through the cladding and its fixings to the structure and may include such items as street lamps, advertisement signs and air-conditioning units. Particular care is required if a flag pole is to be fixed to the cladding rather than directly to the structure because of the dynamic wind forces that may be imposed.

5.5.2 Internal surface loads

Hung cupboards, wash basins and bookshelves can all exert significant loads per unit area of wall. Typical magnitudes of loads are given in Table 5, BS 8200.

5.6 Fire-induced loads

It should be noted that loads may be exerted on the cladding and its fixings due to either its own or the supporting structure's expansion during a fire. This can lead to collapse or detachment of cladding.

In addition, the possibility of fire hose water being absorbed by insulation within the cladding, so increasing the overall self-weight, should be noted.

5.7 Seismic loads

Seismic loads are dependent on the geological region/country in which the structure is located. The necessity of checking this load case may also be dependent on the function of the structure, e.g. a nuclear power station. The consequences can be disastrous if the presence of cladding unintentionally stiffens the structure locally or restrains the free deformation of certain elements. In the past some structures have survived seismic occurrences but the non-structural cladding has fallen away as the result of high storey drift of the main structural frame. Liaison and detailing are therefore critical.

5.8 Blast loading

If it is the wish of the client that the performance of cladding be considered under conditions of blast loading, then the engineer may need to take advice from an expert in that field.

The assessment and level of risk of an internal or external explosion is usually carried out by a risk assessment specialist who will provide information to the engineer which will allow the determination of the forces to be applied to the cladding and the structure.

Cladding and its fixings can be very vulnerable to blast and may be damaged over a wide area. Casualties can be caused by flying debris emanating from disintegrating cladding, including glass.

5.9 Temporary loads

It is necessary to consider how the cladding units are to be handled during transportation to and on site as well as how they are to be stored or stacked.

5.10 Miscellaneous loads

The dynamic effects of vibration and fatigue are covered in Chapter 7. An example is the excitation by the wind of large panels with inadequate inertia causing the finishes to fail.

The level of supervision should be sufficient to prevent poor site workmanship during construction as this can result in site debris or surplus material accumulating or even being disposed of in the cavities immediately behind cladding. Similarly, if supports such as dowel bars are missed, the units below are forced to carry more load. (See also Chapter 3)

Ponding of water is not generally relevant for this report since it is most significant on flat areas. However, inadequate or blocked drainage holes could result in water building up behind vertical cladding.

Leaking of joints could lead to insulation within the cladding absorbing water and increasing the overall weight of the unit exerting internal pressures.

Differential stresses are caused by:

- environmental differences
- different material characteristics
- settlement.

In the case of an overcladding system to cover an existing system that is deteriorating or that is insecure, load due to spalled debris or fallen panels should be considered.

5.11 References and bibliography

Note: See Appendix B for a listing of full titles of British and European Standards referenced in the text. Some other relevant standards are also listed.

Environmental

The Building Regulations 1991: Approved document A. London: HMSO, 1991. [1992 edition]

Eaton, K.J.: *Buildings and tropical windstorms.* Watford: BRE, 1981. (Overseas Building note, 188)

CP3 Chapter V: part 2: *Wind loads.* London: BSI, 1972

ENv1991 : Eurocode 1 Part 2. (To be published)

Cook, N.J. *The designer's guide to wind loading of building structures: part 2: static structures.* Watford; London: BRE, Butterworths, 1990

BS 6399: Part 3: 1988: *Code of practice for imposed roof loads.* London: BSI, 1988

Anderson, J. M. and Gill, J. R.: *Rainscreen cladding: a guide to design principles and practice.* London: CIRIA; Butterworth, 1988.

The Institution of Structural Engineers. *Appraisal of sports Grounds.* London: IStructE, 1991

BS 6399: Part 1: 1984: *Code of practice for dead and imposed loads.* London: BSI, 1984

BS 8200: 1985: *Code of practice for design of non-loadbearing external vertical enclosures of buildings.* London: BSI, 1985

BS 6180: 1982: *Code of practice for protective barriers in and about buildings.* London: BSI, 1982

Explosions

Moore, J. F. A.: *The incidence of accidental loadings in buildings, 1971-1987.* Watford: BE, 1983. (Information paper 8/83.)

Elliott C. L.: *A design philosophy for the construction of ordinary buildings and installations to resist terrorism and disorder.* MPhil thesis, Royal Military College of Science (Cranfield), Shrivenham, 1990.

The bomb shelter area philosophy. Unpublished information from DoE, 1993

Mainstone, R. J.: *Accidental explosions and impacts: some lessons from recent incidents in Symposium of stability of low-rise buildings of hybrid construction.* London: IStructE, 1978 p.13-23. (Also reprinted by BRE as Current Paper 58/78.)

Mainstone, R. J., Nicholson, H. G. and Alexander, S. J.: Structural damage in buildings caused by gaseous explosions and other accidental loadings, 1971-1977. London: HMSO, 1978. (BRE Report.)

Mainstone, R. J.: *The response of buildings to accidental explosions.* Watford: BE, 1976. (BRE Current Paper 24/76.).

Baker, W.E. et *al.: Explosion hazards & evaluation.* Elsevier, London, 1983.

Biggs, J.M.: *Introduction to structural dynamics.* McGraw-Hill, New York, 1964

Structures to resist the effects of accidental explosions. 1969. (TM5-1300; NAVFAC P397; AFM 88-22.)

Whalley, F.: *The effects of explosions on structures.* Proc.Instn. Civ. Engrs. Structs & Bldgs. 1994 **104** Aug. 325-334.

Seismic

International Association for Earthquake Engineering. *Earthquake resistant regulations: a world list - 1992.* Tokyo: International Association for Earthquake Engineering, 1992.

Dowrick, D. J.: *Earthquake resistant design for engineers and architects.* 2nd edition. Chichester: Wiley, 1987.

Structural Engineers Association of California, Seismology Committee. *Recommended lateral force requirements and commentary.* 5th edition revised. Sacramento: SEAOC, 1990.

International Conference of Building Officials. *Uniform Building Code.* Whittier, Cal.: ICBO, 1991. (1994 edition now available)

Applied Technology Council. National Science Foundation; National Bureau of Standards. *Tentative Provisions for the developmentt of seismic regulations for buildings: a cooperative effort with the design professions, building code interests and the research community* Washington, DC: US GPO, 1978.(ATC3-06;NBS Special Pub1ication 510;NSF Pub1ication 78-8)

Building Seismic Safety Council. *NEHRP (National Earthquake Hazards Reduction Program) recommended provisions for the development of seismic regulations for new buildings (FEMA 95).* Washington, DC: Federal Emergency Management Agency, 1988.

Building Research Establishment. *Building in earthquake areas.* Watford: BRE, 1972. (Overseas Building Note 143.)

Building Research Establishment. *Earthquake risk to buildings in the Middle East.* Watford: BRE, 1982. (Overseas Building Note 190.)

Sharpe, R.L. : *Seismic design of non-structural elements* in: *Planning and design of tall buildings: proceedings of the International Conference.* New York: ASCE, 1972 vol Ia pl l43-.

Bulson, P. S. ed.: *Structures under shock and impact II:proceedings of the second International Conference.* Southampton; London: Computational Mechanics; Telford, 1992.

ENV 1998: Eurocode 8: *Earthquake resistant design of structures. To* be published.

Rosenblueth, Emilio.: *Design of earthquake resistant structures.* London: Pentech Press, 1980.

6 Materials & testing

6.1 Materials

More than fifty materials are identified in this report. It is neither necessary nor Practicable to Provide a detailed comentary on each material since most are adequately covered by British Standards or other authoritative literature. All the materials listed in this report are included in tables 6A1-8 together with principle related standards or other appropriate documentation.

particular attention is drawn to the centre column of each of these tables which highlights problems that can occur in using materials or combinations of materials. Additional guidance is given in Chapter 7.

6.2 Deterioration

6.2.1 Durability

It is important that materials for cladding should be capable of resisting environmental agents without suffering structural damage or unacceptable cosmetic effects. Durability is a complex subject in which the dominant climatic factor may vary from one material to another. For example, some polymers are sensitive to ultra-violet light, which in turn is of little significance for natural stone.

The following are some of the factors which the designer will need to review when considering the durability or design life of a material or assembly of materials:

- environmental, e.g.:
  - temperature range, including freeze-thaw phenomena
  - humidity
  - tainfall, including effect of driving rain
  - snow loading from an adjacent roof
  - ultra-violet light
  - infra-red radiation, which may create surface temperatures markedly greater than that of surrounding air
  - wind (see also Chapter 5)
  - exposure conditions, e.g. marine
- specification of materials (see also Chapter 4)
- workmanship (see Chapter 3)
- detailing (see Chapter 7).

The geographical siting of clad facades may be significant when considering durability. For example, a south facing facade will receive more sunlight than a more sheltered north face.

6.2.2 Compatability

Designers must take care to avoid harmful reactions between materials. Such reactions are often promoted or facilitated by water - usually available in abundance on facades. Some incompatibilities, such as electrochemical reactions between different metals, are well understood and can be avoided by careful detailing. The risk of galvanic action rises with increasing difference in the electrochemical potential of dissimilar metals (see Table 6B).

Less well known examples of non-compatibility include:

- migration of plasticiser from PVC into expanded polystyrene insulation causing embrittlement of PVC
- certain timbers, e.g. oak, which contain sufficient inherent acid to attack metal fixings
- certain metals, e.g. lead, aluminium, which corrode when in contact with alkali mortars.

Other examples of these phenomena are given in Tables 6A1-8 and further information is available in CIRIA publication SP87 *wall Technology.* The tables are not intended to be an exhaustive list of all materials, references and potential problems.

Corrosive agents

Chemical agents such as acids, alkalis and oils can cause rapid deterioration of many of the materials used in cladding.

Corrosion of reinforcement in concrete

In the case of concrete reinforced with mild or high tensile steel, the importance of the host material in providing corrosion protection for the reinforcement cannot be over emphasised. Particular attention should be given to the following:

- Use of aggregates and water with acceptably low levels of chlorides and sulphates (see BS 8 1 10: 1986)
- Limitation of chloride exposure in use, e.g. spray from de-icing salts
- The correct use of admixtures
- Use of low permeability concrete, adequate cover and or coatings to slow down the advance of carbonation.

6.2.3 corrosion

The word ‘corrosion’ is derived from the Latin ‘corrodere’ - to gnaw away. It is a term applied most frequently to metals. It is a process causing surface deterioration of the material when exposed to a reactive environment.

Corrosion technology is a complex area and one where the engineer may be well advised to seek specialist advice. Corrosion takes the forms discussed in the remainder of this section.

Atmospheric corrosion

This is a function of the environment and the material. For example, in a clean rural environment, a relative humidity of about 60% or more is required to cause noticeable rusting. A lesser level of humidity may have the same effect in a more polluted environment.

The corrosion products form a layered structure on the surface, usually consisting of metal oxides and hydroxides. These are generally impure and can retain moisture and water-soluble salts which can accelerate further corrosion. In the case of surface oxidation of metals such as aluminium and copper, the oxidation process may be beneficial in preventing further corrosion.

Bimetallic corrosion

When dissimilar metals are in direct electrical contact in corrosive solutions or atmospheres, corrosion of the more negative metal may be exacerbated with partial or complete cathodic protection of the more positive metal. This phenomenon forms the basis for the protection of metals using sacrificial anodes.

The process of bimetallic corrosion is well researched and very detailed guidance is given for both aqueous and atmospheric conditions in PD 6484. However, it should be noted that the process is extremely complex and that the extent and rate of corrosion in a given situation will be influenced by a number of factors which include the following:

- the corrosion potentials of the two metals forming the couple in the prevailing environment

- the nature and kinetics of the cathodic reaction at the surface of the more positive metal and the nature and kinetics of the anodic reaction at the surface of the more negative metal
- the effective areas of the couple - not necessarily the geometrical areas
- the composition of the electrolyte solution, e.g. rainwater, seawater, polluted atmosphere, corrosive vapours, dissolved chloride or sulphate salts, etc.
- the presence of a film of oxide or insoluble reaction deposit on the anode or cathode
- variations in atmospheric conditions causing periodic wetting and drying of the surface (Note the presence of rust lowers the dew point and further promotes wetting conditions).

A classification of the relative compatibility of different metals is given in Table 6B. This classification takes no account of variation in environment from that stated in the Table and is therefore less complex than that given in PD 6484. The Table is quoted by Shmer, Jarma and Burstein as a suitable simplification for most purposes and based upon a paper by Evans and Rance.

The process of bimetallic corrosion can be prevented by complete electrical insulation. In the case of the fixings for cladding, this may involve the use of suitable bushings, washers and spacers and/or the use of compatible coatings on the fixings themselves, e.g. electroplating, etc.

Crevice, pitting and local corrosion of metals

Crevices arise in many ways, for example, through bad welding details. Pits may be present due to material imperfections or local concentrated electrolytic action. Such defects may be starved of oxygen and can accumulate aggressive environmental substances, thus permitting electrochemical reactions. These reactions cause corrosion.

Stress corrosion

Stress corrosion cracking is the nucleation (formation of a nucleus) and propagation of cracks in a metal under constant stress induced by a specific corrosive environment. The stress may be residual in the metal, as from cold working or heat treatment, or may be an applied external stress.

Practically all structural metals, carbon and low alloy steels, stainless steels, etc. are subject to stress corrosion cracking in some environments. Fortunately, these damaging environments are restricted to a few chemical species, and in general, the working stresses are sufficiently high to limit the likelihood of this type of failure in practice.

6.3 Testing

6.3.1 Aims of testing

It is important that testing is rigorous, and has clear aims, objectives and assessment criteria. To be of value, care must be taken to see that sufficient testing is carried out to be truly representative. For all structural testing, it is essential that a structural engineer is involved in the compilation of the test programme and in the evaluation of the results.

Testing can be classified into three broad categories:

- testing of basic materials.
- testing of cladding elements or fixings for compliance with the specification.
- testing of assemblies of cladding.

These are briefly discussed below in the following paragraphs. Testing may be carried out by a manufacturer, contractor or independent laboratory. There is merit in insisting on third party accreditation, usually NAMAS, of any test facility although this may be more difficult for tests carried out on site. The importance of independent testing or independently witnessed testing cannot be overstated.

6.3.1 Testing of basic materials

Routine tests for physical, chemical and other properties are described in British Standards or other appropriate documentation. Guidance is given in Table 6A to the most appropriate source of information for each material.

Particular care should be taken with polymeric (plastic) materials as formulations are frequently updated.

6.3.2 Testing of cladding elements or fixings for compliance with specification

A wide range of tests exist which can be used to check for compliance with specifications. These include non-destructive tests on elements to be used in a contract or tests to destruction on prototype units. Examples of possible tests include:

- load tests to check the structural integrity stability of a cladding panel
- fire performance
- cover meter tests on reinforced concrete
- pull out tests for fixing bolts
- stress grading tests on timber
- durability tests on stone.

For existing cladding in need of repair or refurbishment, testing may form part of an investigation programme (see Chapter 8). Examples of possible tests include:

- checks for high alumina cement concrete
- inspection of cavity ties using an endoscope
- checks on moisture content of timber.

Brief details of these tests appear in Appendix A, together with references from which to gain further information.

6.3.3 Testing of assemblies of cladding

Such tests are valuable in providing specific information for prototype development and to gain approval of the likely performance of cladding assemblies. They also provide a practical bonus in highlighting pitfalls in the erection procedures. In this connection it is worth noting that, at the time of writing this report a very high percentage of curtain walling assemblies so tested failed to pass a simple test for watertightness. In the worst cases reported it even proved impossible to erect the assembly until considerable modifications were made.

This category of test is usually performed at a specialist laboratory although simplified versions of some tests may be carried out on site. These site tests may include some of those listed in Section 4.3.8. Further information is given in Appendix A.

6.4 References and bibliography

Note: See Appendix B for a listing of full titles of British and European Standards referenced in the text. Some other relevant standards are also listed.

Institution of Structural Engineers. *Appraisal of Existing Structures.* 2nd edition. London : SETO, 1980 (being revised).

Doran, D.K. (ed): *Construction Materials Reference Book.* Butterworth-Heinemann. Oxford 1992.

Wall technology. London: CIRIA, 1992. (Special Publication 87.)

BS 7543: 1992 *Guide to durability of buildings and building elements, products and components.* BSI: London, 1992.

Somerville, G. (ed.): *The design life of structures.* Glasgow: Blackie, 1991.

Biezok, I.: *Concrete corrosion and concrete protection.* 8th edition. Budapest: Akademiai Kiado, 1972.

BS 5950: Part 8 *Code of practice for fire resistant design.* BSI. London: 1990.

PD 6484 *Commentary on corrosion at bimetallic contacts and its alleviation.* BSI. London: 1990.

Ryan, P. A. et al.: *Durability of cladding.* London: Thomas Telford 1994

Cox, R.N., Kempster, J.A. and Bassi, R.: *Survey ofperformance of organic-coated metal roofsheeting.* Garston: BRE 1993

Klosowski, J.M.: *Sealants in construction* New York and Basel. Marcel Dekker,Inc.

Browne, R.D. and Elliott, R.L.: *New directions in cladding evaluation in Europe.* Paper presented at C1OB Cladding Conference, Singapore, 1990

Browne, R.D. and Elliott, R.L.: *The testing and evaluation ofcurtain walling systems.* Paper presented at RIBA. London, 1991

Matthews, R.S., Bury, M.R.C. and Redfearn, D.: *Investigation ofdy-namic water penetration tests for curtain walling.* Paper presented at Wind Engineering Society Conference, Warwick University, 1994.

Gedge, G.: *Corrosion: is there a problem?* Arup Journal.

Table 6A Potential problems related to cladding and fixing materials

NOTE: (T) denotes test procedure

Table 6A1 Metals

Material	Potential problem	Material references
Stainless steel (including reinforcement in concrete)	Corrosion Embrittlement Welding Ductility Surface appearance variation	BS 970 (Part 1) BS 1449 (Part 2) BS 4872(Part 1)(T) BS 6105 BS 6744 BS 7475
Galvanised steel (including reinforcement in concrete)	Possible distortion during hot dip galvanising Potential hydrogen embrittlement when galvanising high yield steel Corrosion corrosion in wet concrete	BS 729 BS 1706 BS 6830 DP 8298 BSEN 10147
Mild steel (including reinforcement in concrete)	Corrosion	BS 1140 BS 2996 BS 4466 BS 6265 BS 9590 (Part 2) BSEN 101030
High yield steel (including reinforcement in concrete)	Corrosion Ductility Welding Bending Hydrogen embrittlement	BS 481 (Part 2) BS 4466 BS 4486 BS 4853 BS 5896
Silicon aluminium bronze	Machineability Corrosion	BS 1400 BS 1814
Phosphor bronze		BS 1724 BS2061
Manganese bronze	Not recommended for structural applications due to corrosion susceptiblity	
Aluminium	Discolouration Corrosion Embrittlement Alloyidentification	BS 1161 BS 1470 BS 1474 BS 1475 BS 1490 BS 1615 BS 2569(T) BS 2901 (Part 4) BS 3083 BS 3451 BS 4868 BS 4872 (Part 2) BS 4873 BS 5599 BS 616l(T) BS 6496 BS 6536 BS 6830 CP 118 CP 143 (Part 1) CP 143 (Part 15)
Lead	Corrosion Discolouration Brittleness Creep	BS 6915
Zinc	Susceptible to chemical attack Inadequate galvanising care required if in contact with cementitious materials	BS 729 BS 849 BS 1706 BS 3083 BS 4652 BS 4921 BS 6561 BS 2569 (Part 1) BSEN 10142 CP 143 (Part 5)
Copper	Discolouration Work hardening Corrosion	BS 2870 BS 2874 CP 143 (Pt 12)

Table 6A2 Cementitious materials

Material	Potential problems	References
Concrete, insitu and precast, including concrete bricks, blocks, tiles and reconstructed stone	Mix, e.g. cements, admixtures, aggregates, water proportion, etc. Durability Site blended cements Workmanship Carbonation Chlorides ASR Mundic Chemical attack e.g. sulphates sugars, etc. Shrinkage	BS473 BS1217 BS6073 BS6457 BS8110
Concrete-high alumina cement (HAC)	All of the above plus: Conversion Accelerated carbonation	BS915 BRE Digest 392
Glass reinforced cement	Thermal movement Aging	BS6432 BRE Digest 331
Mortar & render	Mix (as concrete) Durability (as concrete) Workmanship (as concrete) Chemical attack (as concrete) Sand grading Substrate and key Shrinkage Strength of successive coats	BS1369 BS4551 (T) BS4721 BS5262 BS5838 (2) BS6319 BS6472 BS8000 (10) DD88 (T)

Table 6A3 Ceramics and silicates

Materials	Potential problems	References
Clay bricks, blocks & tiles, terracotta and faience (For additional information on masonry see 8.4.7)	Expansion/shrinkage Durability Efflorescence Chemical attack (eg sulphates) Frost susceptibility Inclusions Maintainability	BS402 (Part 1) BS3921 BS5080 (Parts 1 & 2) BS5385 (Part 2) BS5628 BS6431 BS6270 (Part1) BS6477 BS6649
Calcium silicate bricks (For information on masonry see 8.4.7)	Shrinkage Durability Porosity Chemical attack Efflorescence	BS187
Glass (including toughened and laminated)	Viscous flow (creep) Inclusions Thermal movement Working toughened glass	BS952 (Part 1) BS6206 (T) BS7030 (T) PD6512 (Part 3) D. Button 'Glass in Building' R. Kinnear Breaking glass New Builder, Feb 1993

Table 6A4 Stone

Material	Potential problems	References
Natural stone e.g. Limestone Sandstone Marble Granite Slate	Alkalinity and high permeability Delamination Thin slabs susceptible to bowing Durability, e.g.erosion, weathering, contour scaling	BS5080 BS5390 BS5642 BS8298

Table 6A5 Timber and timber product

Material	Potential problems	References
Timber and products	Moisture content Incorrect grade Durability e.g. preservation, avoidance of insect attack etc.	BS 476 BS 4169 BS 5268 BS 6446 BS 6952

Table 6A6 Polymers

Material	Potential problems	References
Fibre reinforced plastic	High thermal expansion Exposure to ultraviolet light	BS 476 BS 6132
Unplasticised polyvinyl choloride (uPVC)	Fire Crazing Identification Formulation change	BS 476 BS7 412 BS7 413 BS7 414 BS4 576
Polycarbonate		BS 476 ISO 179/10 (T)
Epoxy coating of reinforced	Perforations Bending Bond	British Steel Strip Products 'Enhanced Performance' report. Newport 1994 BRE information Paper 193
Coating to steel sheeting	Cut edges Perforations	Durability of cladding profiled metal sheeting

Table 6A7 Jointing materials (sealants and fillers)

Material	Potential problems	References
Polysulphide Polyurethene Neoprene Butyl mastic Putty	Workmanship Staining of adjacent materials Elasticity and compressibility Embrittlement due to ultraviolet exposure Should prove part of properly designed joining system Specific design life Liable to vandalism	BS 544 BS 2752 BS 3379 BS 3712 (Parts 1, 2, 3 & 4) BS 4021 BS 4254 BS 4255 BS 4840 BS 4841 BS 5215 BS 5241 BS 5375 BS 6213 BS 6463(T) BS 6586 BS 6956
Non asbestos fibre		BS 7531
Silicone rubber		BS 5889 BSEN 2830 BSEN 28339(T)

Table 6A8 Adhesives and bonding agents

Material	Potential problems	References
Bonding agents for gypsum	Formulation	BS 5270
Plasters and screeds	Mix proportions Workmanship	
Ceramic tiles and mosaics	Curing time	BS 5980
Non-structural adhesives for wood	Compatibility of elastic modulus	BS EN 204 & BS EN 205 (T)
Phenolic & aminoplastic for plywood	Differential movement	BS 1203
Phenolic & aminoplastic for wood		BS1204
Polyvinyl acetate for wood		BS 407
Resin & polymer cement		BS 63 19 (Part 7) (T)
Silicone rubber (see table 6A7) above)		CEN TC 104 WG8

Table 6B Degree of corrosion at bimetallic contacts

Metal considered \ Contact metal		1 Gold, platinum, rhodium, silver	2 Monel, inconel, nickel-molybdenum alloys	3 Cupronickels silver solder, aluminium bronzes, tin bronzes, gunmetals	4 Copper, brasses, 'nickel silvers'	5 Nickel	6 Lead, tin and soft solders	7 Steel and cast iron	8 Cadmium	9 Zinc	10 Magnesium and magnesium alloys (chromated)	Stainless steel			14 Chromium	15 Titanium	16 Aluminium and aluminium alloys
												11 Austenitic Fe -18 Cr -8Ni	12 Fe -18 Cr -2Ni	13 13% Cr			
1	Gold, platinum, rhodium, silver	-	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
2	Monel, inconel, nickel-molybdenum alloys	B	-	A	A	A	A	A	A	A	A	A	A	A	A	A(x)	A
3	Cupronickels, silver solder, aluminium bronzes, tin bronzes, gunmetals	C(k)	B or C	-	A	A	A	A	A	A	A	Borc	B	A	B or C	B or C	A(e)
4	Copper, brasses, 'nickel silvers'	C(k)	B or C	B or C(g)	-	B or C	A	A	A	A	A	B or C	B or C	A	B or C	B or C	A(e)
5	Nickel	**C**	B	A	A	-	A	A	A	A	A	B or C	B or C	A	B or C	B or C	A
6	Lead, tin and soft solders	**C**	B or C(t)	B or C (q)	B or C (q)	B	A or C (r)	A or C(r)	A	A or C(r)	A	B or C	B or C	B or C	B or C	B or C	A
1	Steel and cast iron (a)(f)(w)	**C**	C	C	C	C(k)	-	-	A(m)	A (m)(l)	A	C	C	C	C(k)	C	A(m)
8	Cadmium (u)	**C**	C	C	C	C	C	C	-	A	A	C	C	C	C	C	B
9	Zinc (u)	**C**	C	C	C	**C**		C	B		A	C	C	C	**C**	C	C(j)
10	Magnesium and magnesium alloys (chromated) (b)(a)	D	D	D	D	D	C	D	B or C	B or C	-	C	C	C	**C**	C	B or C (c)
11	Austenitic stainless steel Fe-18Cr-8Ni	A	A	A	A	A	A	A	A	A	A	(v)	A	A	A	A	A
12	Stainless steel Fe-18Cr-2Ni	C	A or C(s)	A or C(s)	A or C(s)	A	A	A	A	A	A	A	(v)	A	A	(o)	A
13	Stainless steel 13%C	C	C	C	C	B or C	A	A	A	A	A	C	C	(v)	C	C	A
14	Chromium	A	A	A	A	A	A	A 1	A	A	A	A	A	A	-	A	A
15	Titanium	A	A	A	A	A	A	A	A	A	A	A	A	A	A	-	A
16	Aluminium and aluminium alloys (n)(a)(w)	D	C	D(e)	D(e)	C(k)	B or C	B or C	A	A	A(c)(h)	B or C	B or C	B or C	B or C (d)	C	(v)

Notes to Table 6B

A The corrosion of the 'metal considered' is not increased by the 'contact metal.'

B The corrosion of the 'metal considered' may be slightly increased by the 'contact metal.'

C The corrosion of the 'metal considered' may be markedly increased by the 'contact metal.' (Acceleration is likely to occur only when the metal becomes wet by moisture containing an electrolyte, e.g. salt, acid, combustion products, etc. In ships, acceleration may be expected to occur under in-board conditions since salinity and condensation are frequently present. Under less severe conditions the acceleration may be slight or negligible.)

D When moisture is present, this combination is inadvisable, even in mild conditions, without adequate protective measures.

(a) The exposure of iron, steel, magnesium alloys and unclad aluminium-copper alloys in an unprotected condition in corrosive environments should be avoided whenever possible even in the absence of bimetallic contact.

(b) The behaviour of magnesium alloys in bimetallic contacts is particularly influenced by the environment, depending especially on whether an electrolyte can collect and remain as a bridge across the contact. The behaviour indicated in the table refers to fairly severe conditions. Under conditions of total immersion or the equivalent, magnesium alloys should be electrically insulated from other metals. In less severe conditions complete insulation is not necessary, but steel, brass and copper parts should be galvanised or cadmium plated, and jointing compound (D.T.D.369A) used during assembly. Under conditions of good ventilation and drainage, contacts classified as D have given satisfactory service, e.g. brass and steel push-fit and cast-in inserts in magnesium castings.

(c) Where contact between magnesium alloys and aluminium alloys is necessary, adverse galvanic effects will be minimised by using aluminium alloys containing little or no copper (0.1% max.).

(d) If in contact with thin (decorative) chromium plate, the symbol is *C,* but with thick plating (as used for wear resistance) the symbol is *B.*

(e) When contacts between copper or copper-rich materials and aluminium alloys cannot be avoided, a much higher degree of protection against corrosion is obtained by first plating the copper-rich material with tin or nickel and then with cadmium, than by applying a coating of cadmium of similar thickness.

(f) The corrosion of mild steel may sometimes be increased by coupling with cast iron, especially when the exposed area of the mild stee1 is small compared with the cast iron.

(g) Instances may arise in which corrosion of copper or brasses may be accelerated by contact with bronzes or gunmetals, e.g. the oorrosion of copper sea-water-carrying pipelines may be accelerated by contact with gunmetal valves, etc.

(h) When magnesium corrodes in sea-water or certain other electrolytes, alkali formed at the aluminium cathode may attack the aluminium.

(j) When it is not practicable to use other more suitable methods of protection e.g. spraying with aluminium, zinc may be useful for the protection of steel in contact with aluminium, despite the accelerated attack upon the coating.

(k) This statement should not necessarily discourage the sue of the 'contact metal' as a coating for the 'metal considered,' provided that continuity is good; under abrasive conditions, however, even a good coating may become discontinuous.

(I) In most supply waters at temperatures above about 60° C , zinc may accelerate the corrosion of steel.

(m) In these cases the 'contact metal' may provide an excellent protective coating for the 'metal considered', the latter usually being electrochemically protected at gaps in the coating.

(n) When aluminium is alloyed with appreciable amounts of copper it becomes more noble and when alloyed with appreciable when alloyed with appreciable amounts of zinc or magnesium it becomes less noble. These remarks apply to bimetallic contacts and not to inherent corrosion resitance. Such effects are mainly of interest when the aluminium alloys are connected with each other.

(o) No data available.

(p) In Some immersed conditions, the corrosion of copper or brass may be seriously accelerated at pores or defects in tin coatings.

(q) In some immersed conditions, the corrosion of copper or brass may be seriously accelerated at pores or defects in tin coatings.

(r) When exposed to the atmosphere in contact with steel or galvanised steel, lead can be rapidly corroded with formation of PbO at narrow crevices where the access of air is restricted.

(s) Serious acceleration of corrosion of Fe- 18Cr-2Ni stainless steel in contact with copper or nickel alloys may occur at crevices where the oxygen supply is low.

(t) Normally the corrosion of lead-tin soldered seams is not significantly increased by their contact with the nickel-base alloys, but under a few immersed conditions the seams may suffer enhanced corrosion.

(u) The corrosion product on zinc is, in certain circumstances, more voluminous and less adherent than that on cadium. Where this is known to be the case, it should be borne in mind in making a choice between these two metals.

(v) These joints are liable to corrosion in crevices where these are not filled with jointing compound.

(w) Corrosion products from iron or steel reaching aluminium, or corrosion products from aluminium reaching iron or steel, may sometime cause serious local corrosion through oxygen screening or in other ways, even when the total destrution of metal is finished.

(x) The corrosion of Monel can be increased under immersed sea-water conditions.

Table and notes reproduced from *Corrosion Metal/Environmental Reactions; Vol. 1,* by kind permission of Butterworth Heinmann.

7 Design and detailing

7.1 Introduction

The majority of modem buildings are clad with an outer layer suitable for facing the external environment, i.e. a climatic overcoat. These outer layers are generally non-loadbearing, yet must be capable of resisting all types of building movement.

A basic requirement of cladding is that its support and restraint has to be provided by the main structure. It is important to realise that with any cladding system, once in position and the building complete, access to the fixing is usually not possible and therefore complete and durable reliability of design, material and workmanship has to be provided.

Cladding can take many forms, either functional, decorative or both. Common materials used in cladding comprise:

- boards (other than timber)
- concrete, e.g. precast panels, blockwork, etc.
- facing brickwork, including brick slips
- faience and terra-cotta
- glass
- glass curtain walling
- glass fibre reinforced cement (GRC)
- glass reinforced plastic (GRP)
- metal sheeting
- renders
- slates
- stone
- tiling and mosaics
- timber facing.

Composite panels can consist of combinations of the above materials and are dealt with in section 7.8. This Chapter deals with the principles of face-sealed and rainscreen cladding and gives particular attention to the design and detailing of fixing and fastening.

Although the functional requirements of fixing design have become more demanding in recent years, the basic concepts have not altered. Modem fixing design calls, ideally, for non-ferrous materials to be used and stainless steel generally satisfies this requirement.

All facing materials need to be jointed vertically and horizontally and these joints must coincide with the main building expansion joints or be able to move freely across the joints. There will generally need to be more joints in the facade than in the main building structure.

One cardinal rule to observe for any cladding element, except in the case of metal cladding, is that elements such as stone, concrete or GRC should be rigid at one point and supported at two points only. The introduction of a third support point invariably leads to unpredictable uneven distribution of load on the support elements and possible overstress of the cladding unit or fixings.

Units should normally be supported symmetrically but, if out of balance loading is unavoidable, restraint members should be designed to to avoid eccentric loading. This particularly applies to end units which oversail a structure, or a large cornice or parapet stone. Individual units should normally be restrained only at four points. The loadbearing fixing, if suitably designed, can also act as a restraint and take the place of any individual restraint.

The stresses induced by movement due to temperature effects are more fully appreciated these days, although this was not the case a few years ago. These account for many of the brickwork and stone cladding failures of the past. However, there are other movements such as elastic compression of the structural frame, sway due to wind, deflection of supporting members and relative building orientation and moisture effects. The latter consideration is most important in respect of GRC. In the early days of its development, advantage was taken of its lightness and manufacturing flexibility. As a consequence, large complex units were manufactured in dark colours. These combinations gave rise to several failures.

Atmospheric pollution can have an effect. Rainfall, temperature, humidity, chemical pollution are all aspects which need to be considered, not only from the cladding material point of view, but also because of possible effects on the fixings. Too often these points are overlooked. Location within the building is important, in swimming pools, for example.

The shedding of water and the protection of cladding from the environment are important in safeguarding the integrity of systems and materials. Marine environments need specific attention.

Brittle or rigid finishes should be avoided or specially detailed on any walls subject to shear deformations. This applies to materials such as stone facings or most plasters. In Japan, it is recommended that stone facings should not be used on walls where the storey drift is likely to be more than 1/300.

In Chapter 3, the process of design and erection of cladding is described as a team effort. Although the design of cladding and fixings should ideally be entrusted to one engineer, good communication between the parties is essential where these are under separate responsibility. For successful solutions an engineer should aim for simplicity, robustness and standardisation. It should always be remembered that the cost of subsequent replacement of defective cladding may well exceed the cos of the original building.

7.2 Loadings

Design loadings are considered in detail in Chapter 5.

7.3 Movements

The engineer should allow for relative movement between cladding and its support structure. Cladding will generally be subject to a different degree of exposure to that of the support structure. Movements will occur for a variety of reasons that include:

- loading, as considered in Chapter 5, e.g. elastic shortening, lengthening deformation, deflection and creep
- settlement, e.g. long term distortion of frame caused by consolidation of clay sub base
- subsidence or heave, e.g. from mining, etc.
- environmental, e.g. temperature, moisture, etc.
- material dimensional changes, e.g. concrete shrinkage and long term expansion of brickwork, etc.
- deflections, etc. should be limited to resist water penetration

- corrosion - movement due to increased volume of corrosion products - see also section 6.2.3.

Corrosion should be prevented or at least minimised. Other movement should be accommodated in properly designed, detailed and sealed joints executed to a high standard of workmanship. The importance of joints, their distribution and sizing cannot be over-emphasised. The effect of even small movements on unjointed cladding can be devastating.

The design of joints must also take account of the:

- dimensional accuracy of cladding units, e.g. manufacturing tolerances
- accuracy and position of frame
- accuracy of erection process.

Guidance on the design of joints is given in BS 6093.

7.4 Fire resistance and prevention of fire spread

Building Regulation B3 makes it necessary to prevent fire spread through the cladding between buildings and to inhibit the unseen spread of fire and smoke within a concealed space. The external wall construction 'should not provide a medium for fire spread if it is likely to be a risk to health and safety'.

Guidance is given on the requirements for cavity barriers for voids in external cavities in sections 9 and 12 of the Approved Document B. This includes those which are drained and ventilated and which are on buildings over 20 m above ground level and used for residential or institutional purposes. The Approved Document also gives guidance on the details of construction of cavity barriers as well as their spacings. Special provisions apply to traditional masonry cavity walls.

The combustibility of external wall surfaces should be controlled in accordance with the height and boundary distance of the building. This also applies to overcladding.

A BRE report, (Harrison, H. W., Hunt, J. H.,Thomson, J.: Overcladding exterior walls of large panel system dwellings 1986), draws attention to the fact that the effectiveness of cavity barriers may depend upon the degree of distortion of the framing if subjected to fire in the cavity. This should be taken into account if a combustible insulation material is to be used.

Areas of non-fire protected cladding, such as window and door openings, are restricted by the Approved Documents in relation to their height and distance from the boundary.

Further guidance is given in *Fire protection of structural steel in building*, published jointly by the ASFPCM and the Steel Construction Institute.

7.5 Site and construction considerations

7.5.1 Fabrication or manufacture

An engineer should have a good appreciation of fabrication techniques. This can only be gained by direct contact with fabricators. In respect of metal fabrication, a complete catalogue of fabrication practice is beyond the scope of this report but the following is given for guidance:

- metals may be supplied in strip, coil, sheet, wire, rod or bar form
- support brackets, cramps and ties may be sheared, pressed, stamped, rolled or of welded construction
- all welding should be executed by registered welders
- special techniques are required to weld stainless steel
- distortion due to weld stresses in fabricated metal sections may occur as pieces are released from a jig
- when metal is bent, work hardening occurs; unless a section is stress relieved, welding should not be attempted as embrittlement may ensue
- castings are used for some smaller items. Flaws may occur in sand castings of some alloys.

Designers should note that few specialist foundries still exist so costs of casting may be prohibitive. Casting of bronze may need to be larger than strictly necessary from strength considerations.

A practical limit on length of 2.5m should be maintained for support angles. If these are cold formed by pressing, then bend radii should not be less than 3 times the metal thickness. Smaller radii can be achieved on thin section material but this is not recommended as splitting or cracking may occur due to overbending. A minimum metal thickness of 8mm is recommended.

The following points are important in the manufacture of precast reinforced concrete units:

- particular care must be taken by using spacers to maintain correct cover to reinforcement
- tying wire must be kept well back from the surface otherwise rust staining may occur
- stainless steel, galvanised or epoxy coated reinforcement may be considered as an alternative in some circumstances to mild or normal high tensile steel as reinforcement to precast reinforced concrete
- polystyrene void formers used in hollow precast concrete units must be securely anchored to retain dimensional accuracy of the concrete
- consideration of drainage holes should be given to avoid water retention.

7.5.2 Construction and site realities

Ideally, cladding requirements should be discussed at the concept stage of the project. It is also unfortunate that consideration of details is not always addressed at such an early stage.

In the case of brick clad structures, where the outer brickwork skin is built progressively onto the frame, there may be problems relating to:

- the support points
- any floor or structural support level
- any side fixings of the inner skin, in particular to main vertical columns.

It is essential for a dimensional survey of the frame to be made before commencing brick cladding. This survey should be discussed with the responsible engineer so that adjustments to supports may be made if found to be outside agreed tolerances. In an extreme case, sections of frame may need to be re-built.

Often decorative brickwork features or corbelled wall faces are not considered at an early stage and support can sometimes become a problem. It is also unfortunately very common for cast-in fixings to be out of position and for difficulties to arise in relocating the fixing points.

If the construction sequence is considered at an early stage, cast-in sockets or channels in concrete or welded connections onto steelwork can be used. Alternatively, fixing with bolts or chemical anchors is adopted.

Stone cladding is usually considered architecturally at an early stage but actual fixing requirements are not determined. This is mainly because stonework is a specialist package, supplied and fixed by specialist suppliers. The final sub-contract is often not let until the main structure is well advanced. Any special requirements for fixing can also become difficult to accommodate, often leading to sub-frame steelwork being necessary to provide adequate restraint and support (see Fig.7.1).

Brick and stone cladding support design is seldom undertaken by the lead designer, who may not necessarily be the structural engineer (S1, S2). Responsibility may therefore become split and in many cases uncertain.

Although calculations are called for, the lead designer will not always check the design unless the design imposes forces on the

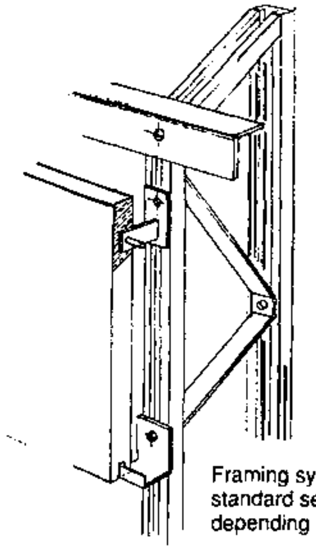


Fig. 7.1 Sub-frame steelwork

structure of which the consultant must take notice. In the case of proprietary cladding systems, these are usually supplied and fixed by one manufacturer and the cladding fixing design is under the control of that company.

Instances can arise where the frame is not in a suitable position or an inner wall is not adequate to provide resistance to the applied forces from the cladding. In such cases, it is sometimes necessary to provide sub-frame steelwork, especially in the case of overcladding. In this case, co-ordination between the design team, cladding supplier and sub-frame subcontractor is essential but often difficult. On some contract arrangements, direct contact between various parties may not be allowed or encouraged and solutions to some problems become not only difficult but can lead to unnecessary delay. This particularly applies where qualitycontrol procedure operate and, unless time is allowed in the programme for strict operating procedures, difficulties can and do arise.

In the case of precast concrete, the engineer is often more directly involved and co-ordination between structure and precast concrete is easier.

It is essential that the use of scaffolding and cranage is made available in order that the correct construction sequence and progress is achieved within programme.

Fixings should be designed to allow sufficient adjustability in three dimensions to accommodate reasonable site discrepancies (see Fig.7.2). This is easy to achieve in the longitudinal and vertical planes but not readily provided laterally, that is across the cavity, especially in the case of loadbearing elements. Threaded components can be used to make restraints adjustable.

7.6 Corrosion

Corrosion of cladding and fixings can and should be prevented by the correct use of materials (see also section 6.2.3). Non-ferrous metals should be used wherever possible. Where, for example, mild steel is used, it should be adequately protected by galvanising or other means. Guidance on this topic is given in the British Steel publication on *Corrosion protection,*

Although stainless steel may be regarded as non-ferrous, it is subject to discolouration in certain aggressive environments. For these conditions, it may be prudent to specify a higher than normal grade of steel, e.g. grades 316 or 321, rather than austenitic 304 S15. Damaged surfaces may show rust marks but corrosion is not progressive with stainless steel .

7.7 Materials and types of cladding

The main materials used for cladding are listed in section 7.1. General guidance on materials is given in Chapter 6. Further key points, particularly in relation to materials used in combination, is given in the following sections concerning individual types of cladding.

7.7.1 Boards other than timber

There are many forms of decorative buildings boards which can visually represent natural stone, exposed aggregate, textured and painted finishes. Some are manufactured as glass reinforced composites claimed to be of high dimensional stability with selected finishes. Others are high pressure laminates or acrylic coated resin bonded timber core.

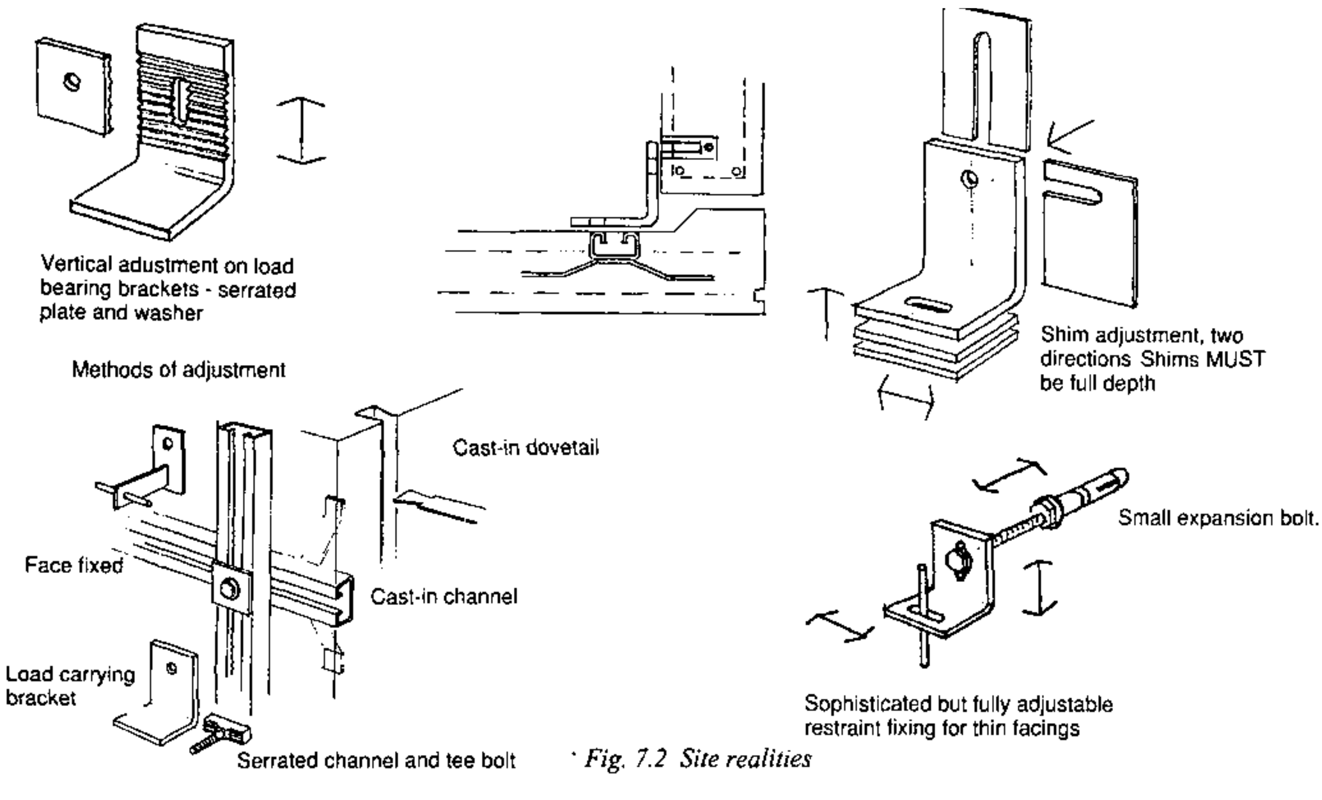


Fig. 7.2 Site realities

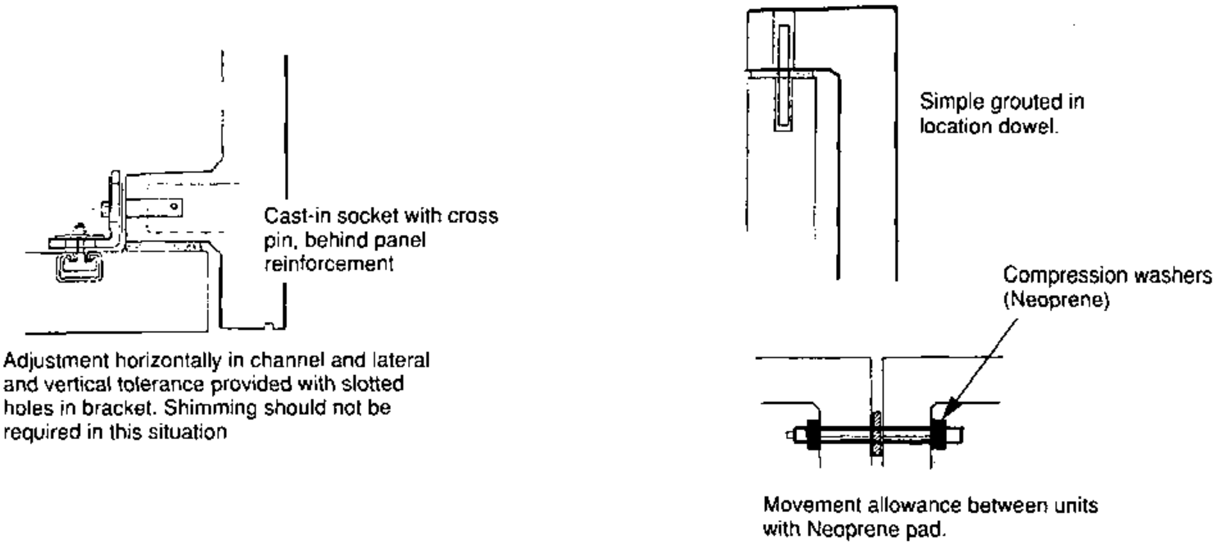


Fig. 7.3 Typicalfixing methodsforprecast concretepanels

It is important to consider fire resistance when specifying such boards. The GRC, high pressure laminates or silicate boards will normally give Class 0, Spread ofFlame. The timber laminates will not provide the required flame spread restrictions.

Boards will normally be fixed onto timber battens with extruded plastic comer or joint profiles. Most boards are highly resistant to weather conditions. When installing high stability boards, compatibility with building movement and movement joints is particularly important.

There is no comprehensive guidance available for this type of cladding. Individual British Standards, where they exist, are listed in Appendix B. Advice should also be sought from specialist manufacturers.

7.7.2 Concrete

Precast reinforced concrete panels

These are usually of normally reinforced concrete but may be prestressed. Reinforced or prestressed concrete panels should be designed strictly in accordance with BS 8110. Further guidance is given in *Precast concrete cladding* by Dr H. P. J. Taylor. Fibre reinforcement is also a possible addition to reinforced concrete but fibres are more generally associated with GRC (see section 7.7.7). Some guidance on fibre reinforced concrete is given in the *Construction materials reference book by* D. K. Doran (Ed) chapter 24. This is one of the heaviest form of cladding and makes far greater demands on fixing attachments than any other material.

Most precast panels are purpose designed but nevertheless the same principles of support and restraint previously described apply and, in particular, the question of movement needs to be carefully considered (see Fig. 7.3). Thermal movements, particularly in precast concrete, if restrained, cause very high stresses in the panels and on the fixings and bearings which provide restraint.

Important factors in the protection of reinforcement against corrosion include:

- adequate effective cover
- quality control
- use of stainless steel, galvanised steel or epoxy coated reinforcement
- handling considerations
- contact between incompatible materials, e.g. reinforcement and fixings
- crack control
- curing.

When designing precast units, due attention should be paid to shape and weight. Although modem equipment can adequately lift very large loads, the positioning ofthe units, often into very confined spaces, is a major problem. Units can easily be damaged by the use of levers to force them into position. A practical and adequate lifting method is required.

It is not always necessary to make up special lifting Frames but care should be taken when lifting with cable, chain or brothers, especially if the units are L-shaped. Units must be lifted about their centres of gravity and the correct positioning of cast-in lifting devices and their adequate tying to reinforcement is essential. Lifting stresses must be considered in the design and may necessitate reinforcement provisions greater than the normal service requirements.

Blockwork

Weather resistant concrete blocks conforming to BS 6073 are readily available. Blockwork in this instance is usually unreinforced and should be designed to BS 5628 Part 1. Should it be necessary to provide reinforcement, this should be in accordance with BS 5628 Part 2. Detailing of blockwork is similar to that for brickwork. One important difference to note is that concrete shrinks with time whereas brickwork may experience long term expansion. Considerable guidance on blockwork is given in the *Concrete masonry designer's handbook* by Dr J. J. Roberts et al.

In-situ reinforced concrete

In-situ reinforced concrete should be designed to BS 81 10. Much of the advice given for precast reinforced concrete and blockwork will apply to in-situ concrete which is rarely used as cladding.

7.7.3 Facing brickwork (including brick slips)

Facing brickwork should generally be designed in accordance with BS 5628 Parts 1 & 2. Such brickwork is usually built on site but can also be preformed into panels in the factory. Unless special provisions are made for differential movement, vertical support should be provided, preferably at each storey but at intervals not exceeding 10m. Careful attention must be given to relative movement between brickwork and the supporting structure. If the support structure is concrete, then the long term movements of frame (shrinkage and creep) and brickwork (expansion) will be in opposition. The design of vertical and horizontal joints to accommodate these movements must be carefully considered. (see Fig. 7.4)

The effective height or length of a loadbearing wall should take account of the relative stiffness of the elements of the structure connected to the wall and the efficiency of the connections. In

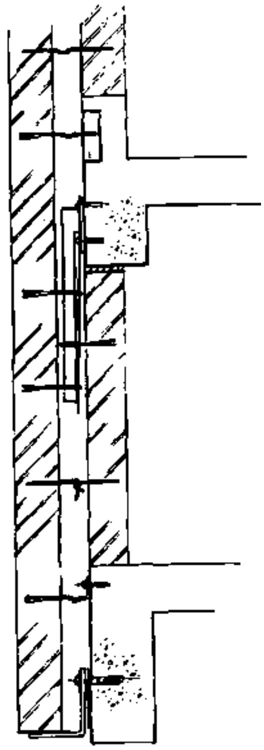


Fig. 7.4 Typical detail of brick facing to concrete brick or block

cavity walls, the height and length of the outer leaf should be restricted to avoid loosening of the ties. This leaf should be supported at intervals of not more than 3 storeys or every 9m, whichever is less. For buildings not more than four storeys or 12 m in height, whichever is less, the outer leaf may be unsupported for its full height. The stiffness of any wall is based on the height to thickness ratio. (see BS 5628 Part 3 1985).

For steel framed buildings, specific guidance is given in *Brick Cladding to Steel Framed Buildings* published jointly by the Brick Development Association and British Steel.

Where the backing structure is itself secure brickwork or blockwork, the facing brickwork must be securely tied to the backing using ties to a specification and spacing in accordance with BS 5628 Part 1 or calculated based upon assumptions suggested in CIRIA Report 117.

Brick slips or cut bricks are sometimes used to face up concrete slab edges or beams. These are not recommended but, if they are used, they should be fixed either by mechanical anchors or a combination of mechanical anchors and suitable adhesives. (See also section 8.4.6)

7.7.4 Faience and terra-cotta

Faience is defined as a glazed terra-cotta (Italian for burnt clay). It is a clay product, fired twice, once with and once without a glaze. It is sometimes provided as large glazed tiles. The term terra-cotta is normally used in connection with un-glazed products. There are no codified guidelines for design but some guidance is given in Mitchell's *Advanced building construction* and McKay's *Building construction volume 4.* There is no British Standard specifically covering this material but some guidance concerning maintenance is given in BS 6270 Part 1. Faience is made in a range of colours including white, cream, rich red, pink, buff and occasionally green/grey.

It is fixed in similar manner to stone work. Blocks may be cast hollow and filled with concrete. Thin faience or tiles of thickness of 35mm may be fixed using wire ties and mortar dabs. Terra-cotta has the great advantage of durability and hardness and is relatively light in weight. A disadvantage is that unequal shrinkage may inhibit good lines in moulded work. Much decorative work is done by hand finishing. As a material, it is fire resistant and non-combustible.

Vitrified ceramic materials are unaffected by ageing, weathering, ultra violet radiation and atmospheric pollution. They are usually made with a minimum compressive strength equivalent to a class B engineering brick. Used as a cladding with ornamental cornices, pilasters, and copings, it may be supported on brackets or continuous angle in the same manner as brickwork or stonework and restrained in the usual way. It can also suffer the effects of water penetration and frost when crazed.

7.7.5 **Glass**

Glass is basically a compound of silicates of soda and lime with other ingredients to provide special properties. It has two significant mechanical characteristics - it is brittle and has wide variability in strength.

Glass is very strong in compression, but its tensile strength is relatively low when compared with its compressive strength. It has no ductility at normal temperatures and gives no warning of impending failure. Surface flaws which arise during manufacture and in service have a considerable effect on the strength of glass. It is recommended that design stresses should be based on statistical analysis of a large number of representative test samples.

There is a large range of glass types available resulting from variations of the manufacturing process adopted to produce the properties most suitable for the required application. There are many factors governing the selection of glass type but, from the point of view of safety, the following factors may apply:

- site location and altitude
- size and form of the building
- total area to be glazed
- height of glazing above head height
- location of panels, e.g. likelihood of impact
- differences in floor level on either side of the glazing
- size of panels
- pitch of glazing
- method of support
- fire resistance requirements
- design wind load, snow load or other actions, including self-weight
- possible free fall of fractured glass, including catchment arrangements
- access for cleaning and maintenance.

Most of the glass currently produced is float glass. This may be annealed, coated, toughened (tempered), heat-strengthened and laminated or a combination of both. Heat-soaking toughened glass reduces the possibility that there might be minute inclusions of foreign particles in the glass supplied which may become a cause of spontaneous rupture in service. In general, therefore, glass normally provided for building facade cladding will be annealed, toughened and heat-soaked or laminated as a basic specification in order to fulfil their structural function.

Due to the temperature gradient between the surface and the centre of a glass pane on cooling, residual compression at the surface provides a degree of tensile and flexural strength. Surface texture has an effect on bending strength but in sound homogeneous glass, strength does not appear to depend on composition. Manufacturers' tables give some strength values based on a risk of not more than 1% failure.

When fixing glass, the material should never be in direct contact with metal but should always have suitable separating gaskets. Glass panels are top hung in many large modern buildings. Despite this, as in other cases, wind stresses are generally critical. Large deflections can take place in large glass panels and although perhaps not dangerous, such movement can be visually and psychologically disturbing. Guidance is given in BS 952 Part 1: BS 6262 and *Glass in Building* ed. D. Button.

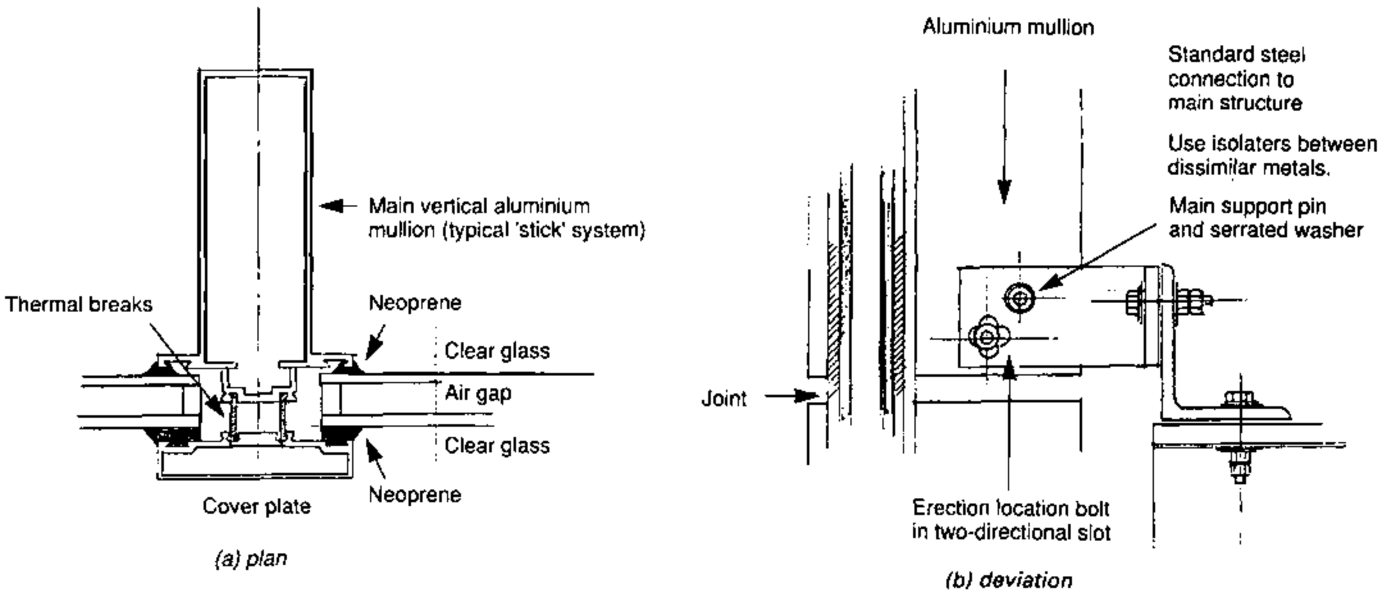


Fig. 7.5 Curtain walling connections

The use of glass as cladding may vary from the simple pane of glass in a window to a highly sophisticated glass facade in which the structural properties of glass are fully exploited. The latter may make extensive use of silicone adhesives. In some systems, stiffening is provided by fins of glass orthogonal to the plane of the facade and bonded to it with structural silicones. This is relatively new technology and should therefore be adopted with particular care.

In an effort to combat terrorist attack, laminated glass or applied films are used to reduce fragmentation. In agreeing to such use, the structural engineer must be satisfied that the supporting structure will not become excessively overloaded in the event of an incident.

7.7.6 Glass curtain walling

This description is given usually to glass used in conjunction with metal mullion systems. The metal for the mullions is usually extruded aluminium alloy, coated steel or stainless steel. Glass sheeting may be interspersed with opaque panels of coated steel or other material. Most curtain walling systems are of a proprietary nature and there is a strong recommendation in favour of testing trial assemblies. Reference should be made to section 6.3.3 and Appendix A for advice on testing. There is no specific British Standard on curtain walling, but comprehensive guidance is given in the Standard & Guide to Good practice for *Curtain Walling* published by the Centre for Window & Cladding Technology. Key points to be addressed by the designer are:

- allowance for vertical movement
- mullions should be designed to resist vertical and horizontal forces
- horizontal deflection of glass in the supporting system
- mullions should provide structural and drainage continuity.

7.7.7 Glass fibre reinforced cement (GRC)

This composite material normally consists of glass fibres in a matrix of Portland cement and fine sand. However, formulations have become more sophisticated and a recent development comprises boro-silicate E-glass in an acrylic polymer modified Portland cement mix.

Advice on design may be obtained from BS 6432, Pilkington Bros. Cem-Fil GRC Technical Data 1985, BE Digest 33 1 and publications by the Glass Reinforced Cement Association (GCRA). Successful use of GRC requires adequate consideration of the factors which influence production of a composite and the range of conditions to which it will be subjected during its intended life.

GRC panels are produced with a variety of finishes including:

- concrete
- decorative (off the mould) colouration.

Problems can arise from:

- top hanging
- failure due to potential long term material strength reduction
- complex shapes
- sandwich panels
- crazing.

Typical support details are shown in Fig. 7.6.

7.7.8 Glass reinforced plastic (GRP)

GRP consists of 'Syrupy' resins which are applied in layers to a moulding surface, together with alternating layers of glass fibre reinforcement which is usually in the form of a 'mat' of chopped strands.

Panels made from this material should be designed Strictly in accordance with recommendations laid down by the National Glass Reinforced Plastics Construction and Engineering Federation (NGRPC). In general, units should be bottom supported.

7.7.9 Metal sheeting

Such sheeting will normally be aluminium alloy, stainless or coated mild steel. Sheets will be either flat or profiled to provide inherent stifiess. In some cases, sheeting will be backed by insulation material. Guidance for the design of steel sheeting is given in BS 5950 Part 6 and for aluminium alloy in CP 1 18 and BS 81 18 Parts 1 & 2. Panel details are shown in Fig.7.7.

Metal sheeting can be provided with a variety of finishes which include:

- plain - matt, bright, pearl or brushed
- textured - leather, linen, embossed, mosaic.

Engineers should take into account both finishes and colour in assessing possible effects of environment on sheeting. Particular problems have occurred with coated mild steel sheeting where corrosion has taken place at cut edges. In a limited number of cases, poor quality organic coatings have been the cause of corrosion. In this respect, there is some evidence to suggest that darker coloured coatings with a high heat retention may be more prone to loss of adhesion than lighter coatings.

7.7.10 Renders

External walls may be rendered for weather protection. Rendering normally consists of two or more coats, the undercoat being about 13mm and the final coat varying from a minimum of 5mm upwards. Before application, the substrate must be dry, free from grease and dirt and any loose material, and be properly prepared. Brick joints should be raked out and the surface serrated to form a key. The main types of rendering, as noted in BRE Digest 196, are as follows:

- pebbledash – this is a rough finish of small pebbles or crushed stone thrown onto a freshly applied coat of mortar.
- roughcast – this is produced by throwing a wet mix containing course aggregate onto the initial render.
- scraped off texture - mainly a decorative finish produced with different tools on the final coat of render at an appropriate stage of setting. The final result will depend on the skill and ability of the operative.
- plain coat - a smooth, generally level surface produced with a wood, cork, or felt faced float.
- machine applied finish – the final coat is spattered onto the face by machine, commonly known as 'Tyrolean.'

Smooth finishes are subject to crazing and can be patchy in appearance. Mixes rich in cement with fine sand and applied with a steel float are more likely to suffer from crazing. Pebbledash and rough cast finishes are ideal in exposed situations, having good water shedding properties, and are less subject to surface cracking. Renders may be applied onto metal mesh to give added key.

The most suitable mixes using correctly graded sand for external work are as follows:

- A: 1 part opc, ½ part lime, 4-4½ parts sand
- B: 1 part opc, 1 part lime, 5-6 parts sand
- C: 1 part opc, 2 parts lime, 8-9 parts sand

all by volume, where A, B and C are the base, intermediate and finishing coats respectively. Masonry cement mixes may be used as alternatives to B & C above and sometimes a water inhibiter will be necessary. The second or any subsequent coat should never be stronger or richer in cement than the base or previous coat. All renders are subject to building movement and adequate jointing should be provided.

Moisture penetration is likely to occur in solid brickwork through the capillaries between mortar joints and the wall units. The more impervious the mortar and the denser the brick or block, the more serious the penetration is likely to be. Dense mortars are more effective in preventing moisture drying out. Dense mortars are more likely to crack, thus allowing moisture penetration. Moisture is more likely to remain trapped behind dense mortar and become evident on the internal wall face.

Further guidance on the use of renders may be found in *Construction Materials Reference Book,* Chapter 21. (ed. D. K. Doran)

7.7.11 Slates

These may be of natural stone or synthetic, e.g. GRC. Design of slated facades should be in accordance with good construction practice. Key points to observe include:

- fixing nails to be non-ferrous
- correct lap length to slates
- treatment of battens with preservative

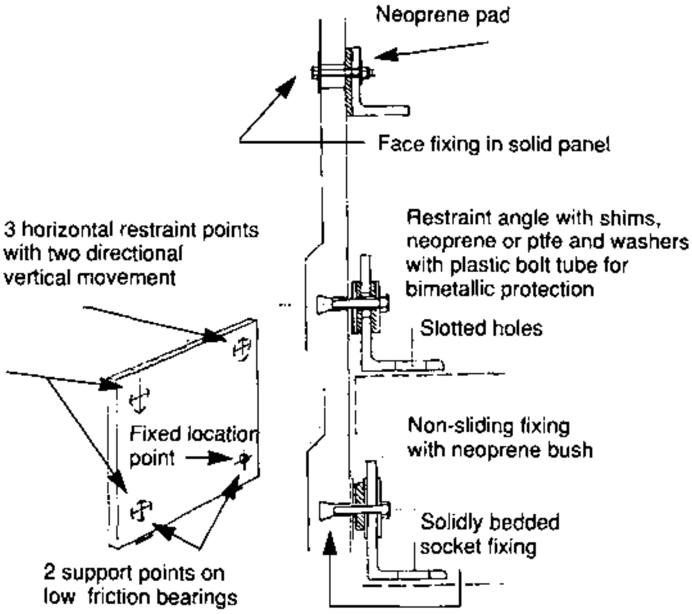


Fig. 7.6 Support arrangements for GRC panels

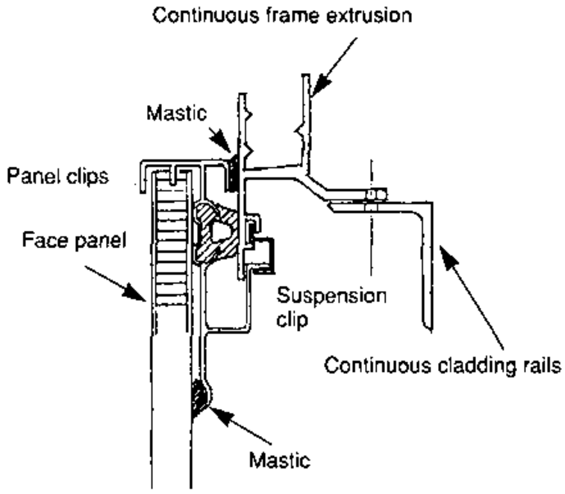


Fig. 7.7 ***Typical metal panel detail***

- substrate to be adequate to support battens
- substrate to be protected by damp proof membrane.

Some synthetic slates have received a British Board of Agrement Certificate. Further guidance is given in BS 5534.

7.7.12 Stone

Natural stone

General guidance on the use of stone may be obtained from BS 5390 and BS 8298. Natural stone for cladding is usually limestone, sandstone, marble or granite. Although much stone is quarried in the UK, a considerable volume is imported. Correct cutting and bedding of material is important. All stratified rocks such as limestone and sandstone were laid down in a series of layers over different periods of time. This naturally led to a variation in the material. The bed joints in sandstone are usually easily identified, but those of limestones are not so clearly defined so a sound knowledge is required to determine natural beds. Selection of stone is usually done on the basis of a particular quarry or colour. Major stone companies have their own detailing facilities and all work is set out to templates before cutting and working (see Fig. 7.8). The advice of experts is essential to avoid wasteful cutting.

The required direction of the bed joints will depend to some degree on the type and position of the stone being cut. For example, arch stones should be set with the bed generally normal to the curve of the arch. This will mean that, at any point in the arch, the arch stones progressively up to the key stone will be correctly bedded to resist the horizontal arch forces. In any case, the most important point is to make sure that the ends of the laminae should be exposed when the stones are placed in the building.

Stone facades may be constructed using material of specified minimum thicknesses in accordance with BS 8298 Table 4 or in thin slabs, usually of marble or granite, supported on metal fixings on sub-frames. The minimum thickness requirements for stone vary according to the type of stone, its fixing and its location within the building and these requirements are set out in detail in BS 8298. Sandstone and limestone slabs up to 3.7m in height should be a minimum of 50mm thick if continuously supported. Granite and marble may be 20mm thick under the same conditions. For heights in excess of 3.7m, the thicknesses must be increased to 75mm and 40mm respectively.

Generally, sedimentary limestones will need to be supported every storey height or at suitable convenient structural levels in order to give economic design solutions. Granites and marbles should be similarly supported, although it is possible to support the thinner stones separately and individually with suitably designed metal cramps acting as combined loadbearing and restraint members. In the case of the metal framed panels, stones are often reduced to 20mm but this system is not often adopted in the UK. The quality of the stone becomes critical with the flexural strength having to be considered on the basis of adequate testing.

Reconstituted stone

Reconstituted stone is defined as any material manufactured with aggregate and cementitious binder and intended in appearance to resemble and be used in a similar way to natural stone. This material is covered by BS 1217 and BS 6457. This stone is usually fixed in the same way as natural stone, except in small units where it is normally reinforced to control cracking and facilitate handling. A very light mesh is usually specified for flat ashlar-type stones. It is formed in moulds in the same way as precast concrete.

It may be homogeneous throughout or consist of a facing material and a backing concrete. Where a mix containing dissimilar materials is used, particular care should be taken concerning the interaction of dissimilar materials and effective interface bonding. When used as lintels, a design check should be made of the tensile bending stresses between supports.

It is not normally necessary to design fully in accordance with BS 8110 as the elements are not generally loadbearing, although BS 8110 minimum percentages of reinforcement should be considered and due attention should be given to exposure conditions and minimum cover. Some reconstituted stone mixes have greater permeability than structural concrete as envisaged in BS 8110 and carbonation may be a problem in such a case. Care should be exercised in using the phenolpthalein test to determine the depth of carbonation since some reconstituted stone may be highly permeable and contain a high fine aggregate content. In such cases, the test may indicate low carbonation whereas carbonation could be diffuse throughout the entire section. However, if this entails unacceptably large cover, the use of stainless steel reinforcement can be adopted with a smaller cover.

In detailing reinforcement, although it is tempting to use 3 or 4mm bars, in fact the best minimum diameter rod for fabrication is 6mm as this is more controllable for bending and handling. Reinforcement should be kept adequate but very simple in units made of dry tamped mixes.

7.7.13 Tiling

Tiles, which may be of clay or concrete, are usually ribbed and provided with two holes for nailing. Tiles may be plain or,

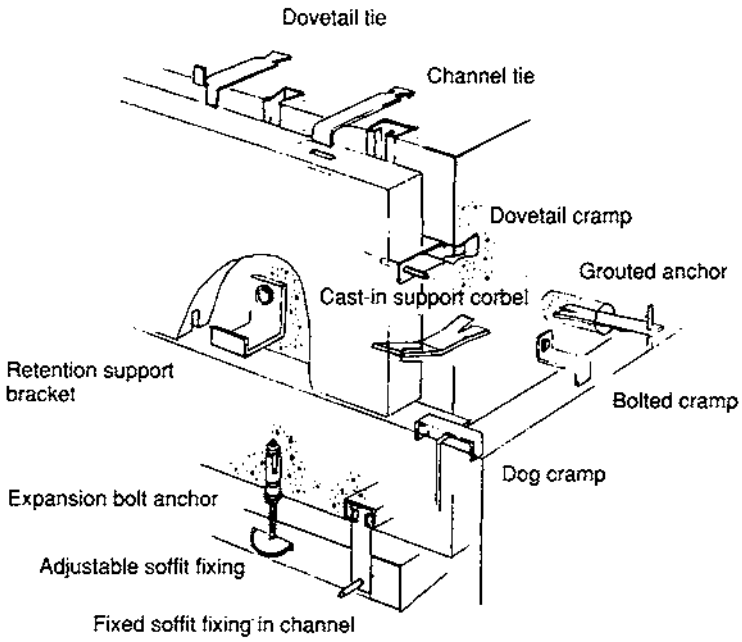


Fig. 7.8 (a) Stone cladding to concrete

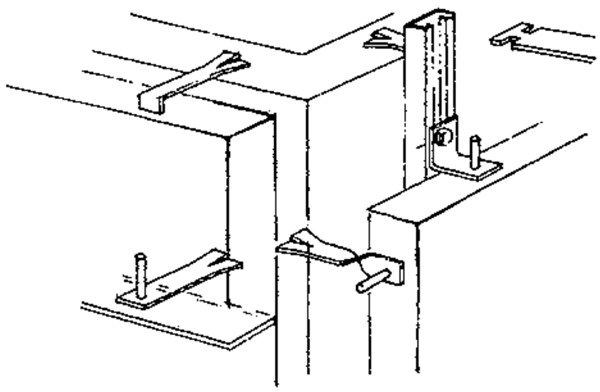


Fig. 7.8 (b) Stonework to brick or blockwork

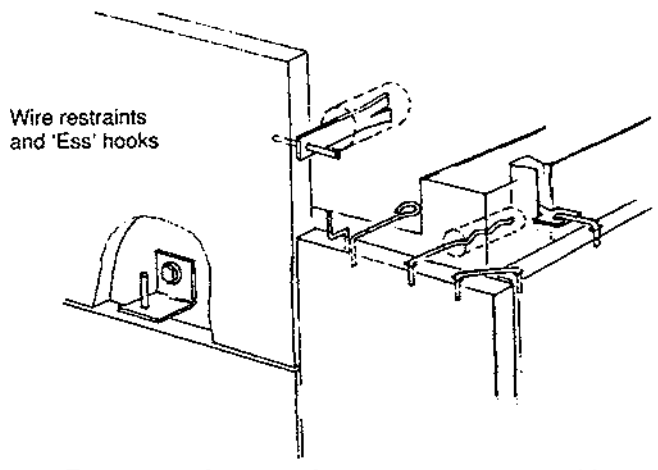


Fig. 7.8 (c) Thin stone facings, e.g. granite, marble, etc.

Fig. 7.8 Stone Fixing details

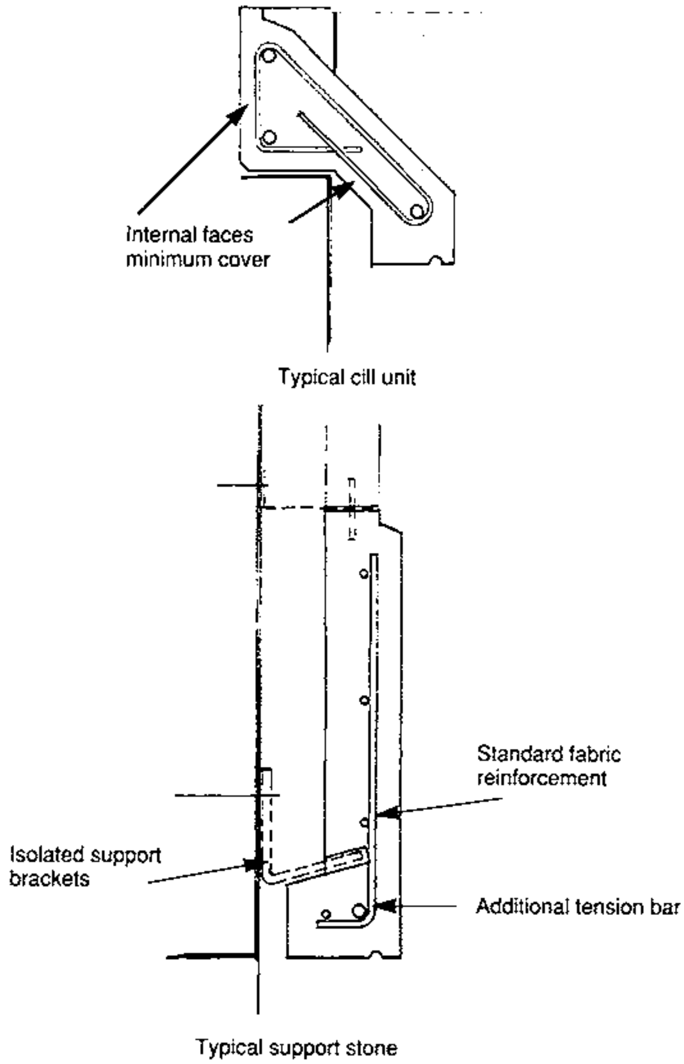


Fig. 7.9 Reconstituted stone details

profiled. Flat tiles are usually used for tile-hanging. In tile-hanging, tiles are fixed to preservative treated timber battens by 38mm nails of aluminium, cut copper, copper wire or zinc. A breather membrane (see BS 4016 & BS 1521) should be laid against a backing wall. Tiles should be laid to overlap every third tile, the setting out parameters being:

- the gauge - distance between battens
- the lap - the overlap of three tiles
- the margin - the exposed portion of every tile.

Glazed ceramic tiles are provided with either an earthenware glaze or coloured enamel. Surfaces may be matt or glossy. The use of small ceramic tiles bonded to a backing with an adhesive is not recommended. (See section 8.2.4 also)

7.7.14 Timber facings

Timber cladding, like decorative boards, may be faced to represent various types of material. Basically, the structural composition of timber claddings will be:

- solid timber
- plywood
- blockboard - 3 ply
- blockboard - 5 ply
- laminboard - standard 5 ply.

Boards are bonded with either urea or phenolic formaldehyde resins. Exterior boards will resist weather, micro-organisms, cold and hot water, stain and dry rot.

Face veneers provide timber finishes of birch or conifer. Veneered boards can be pre-surfaced with the following finishes:

- cellulose impregnated with phenolic resin
- wire mesh patterned overlay on a phenolic resin surface
- heavy or light duty Kraft paper impregnated with synthetic resin for painting
- melamine plastic
- decorative veneers such as afrormosia, khaya, oak, sapele and teak.
- GRP faced panels
- mineral aggregates bonded into epoxy resin coated board
- metal faced with aluminium, copper, steel sheet or foil bonded to the timber
- phenolic or polyester resin impregnated glass fibre coated plywood
- prepainted.

Cladding panels can be formed as timber panels with stiffened edges of any combination and designed as spanning members. (See Fig. 7.10) Timber has the advantage that it can be curved under steam pressure to suit required radii.

As in the case of resin bonded boards, fire resistance is of prime importance. Resistance to fire can be enhanced with impregnation and/or coating with proprietary formulations or by facing with non-combustible foils.

Plywood, blockboards and laminboards meet Class 3 flame spread to BS 476 and panels can be treated with intumescent paint and varnish or by impregnation to upgrade to Class 1 or 2 surface spread of flame.

Timber cladding is flexible and can be used to produce simple as well as complex cladding designs. As with all timber structures, moisture content is important and if the moisture content is consistently likely to exceed the 15% recommendation, reduction factors on the design stresses should be used as noted in the relevant timber standard. Where this percentage is likely to

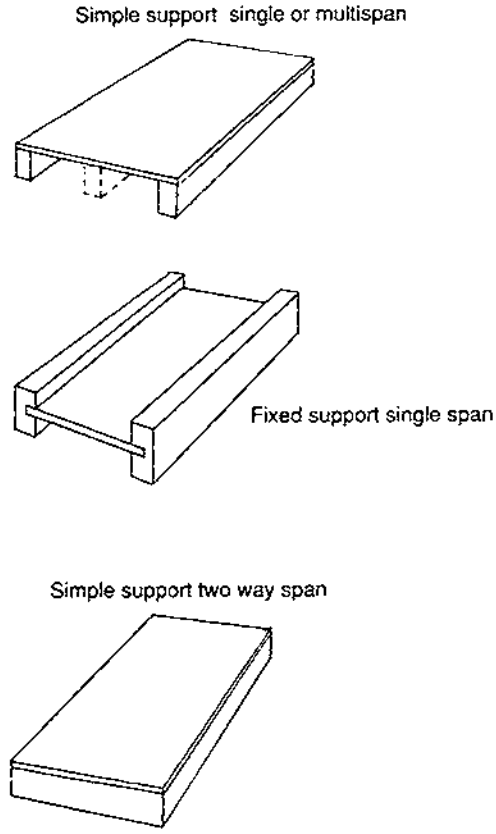


Fig. 7.10 Timber cladding elements

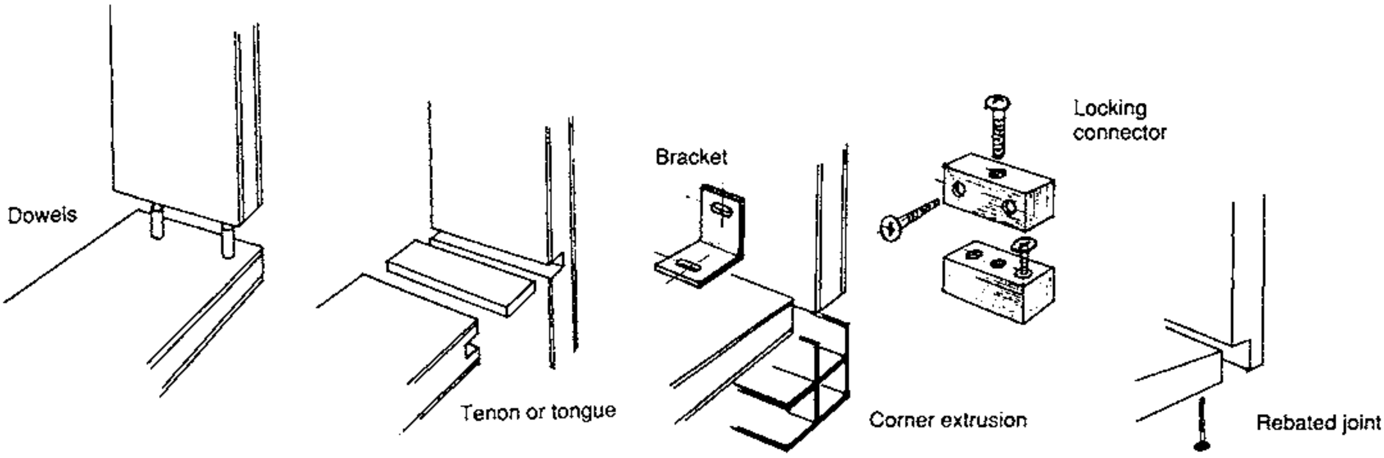


Fig. 7.11 Various types oftimber corner connections

exceed 20%, special pretreatment with preservatives is recommended.

Normal methods ofconstruction (see Fig. 7.1 1) include:

- bolting
- screwing
- dowelling
- hidden tenon tongues
- plastic dual face
- screw blocks
- metal brackets
- extruded plastic stiff comer or joint profiles.

Water based paints should not be applied to blockboard or laminboard and exterior quality paints should always be used for external work. Proper edge treatment of panels is essential to prevent degradation.

Although some guidance regarding the structural aspects of design may be obtained from BS 5268, boards differ in their mechanical properties and details should be obtained from manufacturers.

7.8 Composite faced panels

7.8.1 Stone faced concrete panels

Granite is the most satisfactory material to fix as a stone fascia. Stainless steel dowels should be:

- at least 4.7mmϕ
- provided at a density of 11 dowels/m^2
- inclined at 45°/60° to the face ofthe stone
- alternately inclined upwards and downwards.

Units faced with other natural stone should only be fixed with dowels after satisfactory testing to establish their loadbearing and pull-out strengths. There should be no adhesion between the stone and the concrete backing. This can be achieved by means of a polythene or other similar panel breaker.

7.8.2 Brick faced concrete panels

Bricks with holes may be cut so that the undercut holes form a key for the concrete during the pouring compaction operation. Alternatively, bricks or part cut bricks may be retained with nylon filament, stainless steel wire or stainless steel bars threaded through the bricks. In the latter case, the bars should be tied back to the main reinforcement ofthe concrete unit. Pointing is usually done post-erection.

Tiles have been used but are hard to key and too thin for adequate mechanical restraint and adhesives can fail.

7.8.3 Precast concrete or reconstructed stone faced panels

Precast slabs may be used in the same way as stone or brickwork to face precast or in-situ concrete. This provides an opportunity to use a wide variety of concrete finishes.

7.8.4 GRC panels

Two GRC skins enclosing a suitable core material, such as polystyrene, bead aggregate concrete or injected polyurethane foam can provide insulated units with adequate spanning capabilities. The important point is to prevent moisture penetration from causing differential stresses and deterioration of the panels (see BRE Digest 41 and BRE report 12). Shaped sandwich panels, i.e. curved or parapet panels, should not be specified as restraint of differential moisture and thermal movement between skins can become a problem.

7.8.5 Stone faced (veneer) panels

The use of very thin veneers of natural stone applied to large composite panels of lightweight materials is a comparatively recent innovation and thus experience of their use is limited. Thicknesses down to 4 mm have been used.

Panels are factory produced by sawing through a sandwich, with the stone placed centrally, to form two panels in one operation. The success of this system relies upon very strict quality control due to it's dependance upon the effectiveness of adhesion.

7.9 Rainscreen cladding

The weather face of all cladding, which may or may not have voids behind it, resists wind-blown rain in a number of ways. Systems (see Fig. 7.12) can be categorised according to whether the face is sealed, moderately permeable or very permeable, whether the void behind is narrow or wide, drained or undrained and whether the void constitutes a small or large volume of air between cavity barriers. These factors dictate the air pressure in the void in relation to external pressures.

The rainscreen principle is employed when the face is not sealed and the air permeability of the face is such that there is virtually no air pressure difference between the two sides of the cavity so that water is less likely to cross the void. The inside face of the void must, however, achieve a complete air seal.

Rainscreen cladding is a possible technique for overcladding as well as for new design. It is described in the CIRIA publication ***Rainscreen Cladding*** by Anderson and Gill.

7.10 Fixings, fastenings 81 supports

7.10.1 General

Robust and durable fixings are essential for the success of satisfactory and safe cladding. In many cases, they will be permanently hidden once cladding is in place and the likelihood of inspection and maintenance of fixings will be remote. Therefore, it follows that all fixings should be corrosion resistant. In general, all metal parts should be either non-ferrous, stainless **or** adequately protected mild steel.

Most cladding fixing failures arise from a combination of reasons. These include:

- poor design and/or detailing
- poor workmanship
- inadequate or non-existent communication between the parties involved.

The design of fixings should only be entrusted to suitably qualified and experienced professionals.

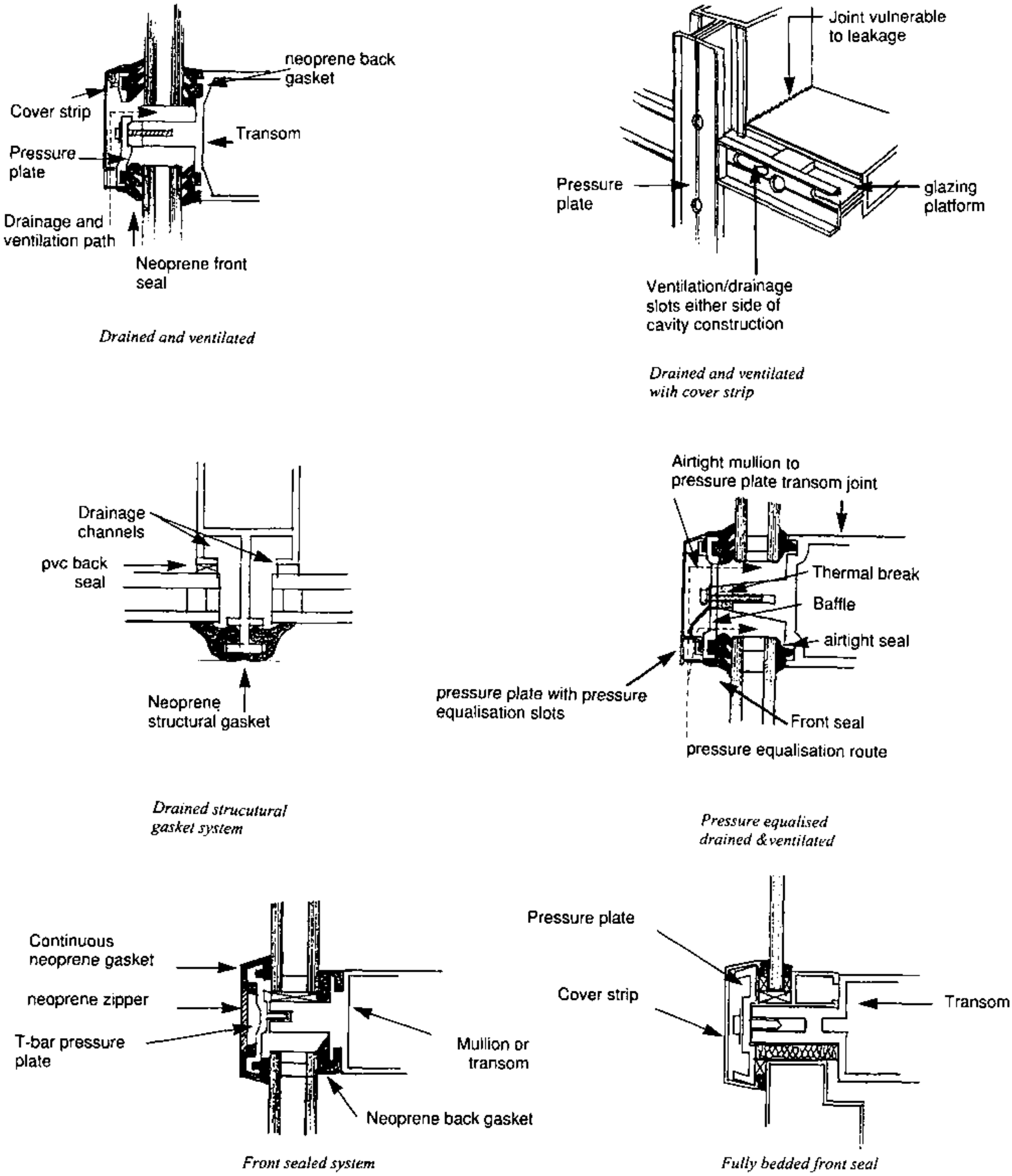


Fig. 7.12 Rainscreen sealing systems

Fixings many be categorised as follows:

- support
- restraint
- support and restraint.

It is important to note that the accuracy of pre-positioning of the fixing element in a structure is extremely critical and invariably gives problems unless there is close co-ordination between the parties responsible for detailing, setting out and construction.

When cast-in elements are used in both the structure and the unit, careful allowance for tolerance needs to be made in the connecting part of the fixing.

7.10.2 Attachment to cladding material

Attachments, (see Fig. 7.13) for example, into precast reinforced concrete, GRC or GRP may include:

- cast-in sockets
- cast-in channels, dovetail slots
- other cast-in recesses or projecting features.

In materials lighter than precast concrete, the attachment may include:

- dowels
- ties
- plates set into mortices and grouted or bolted into position
- through or face fixings
- lipped or nibbed angles set in mortices.

7.10.3 Fixing elements

The majority of fixing elements are formed from metal angle sections which should be suitably protected from corrosion. Mild steel angles may be selected from standard section books but few such sections are available in stainless steel. The minimum thickness for pressed metal angles should not be less than 8mm. Some fixing elements may be produced by casting to the required profile.

Limitations on the length and bending radii of angle supports are given in section 7.5.1. A fixing component consists of three elements:

- the attachment to the structure
- the attachment to the cladding material
- the fixing element itself, e.g. bracket or other support.

Basic considerations can be listed as follows and these will largely dictate the selection of fixing elements:

- the structural material
- the cladding material
- the forces involved, including those due to any incompatibility between the structure and the cladding
- the characteristics of the metal, including availability, workability, durability and compatibility with adjacent materials (see also section 7.10.5)
- the design life of the building
- aesthetic considerations with respect to the visual appearance of exposed fixings
- integrity – this should always take precedence over expediency and cost.

7.10.4 Attachment to structure

There are a variety of ways in which this attachment can be made. The type of fixing may be influenced by the stage at which the attachment is made. For example, it is, unfortunately, often the case that no provisions for fixing have been made prior to frame erection. Attachments to structure include:

- drilled-in expansion or undercut bolts
- resin anchors
- injected grout type fixings
- ties, cramps corbel plates and other devices which are morticed into position
- surface mounted channels or other sections
- by bolting or welding to steelwork.

If pre-positioned fixings are an option then the choice will include:

- cast-in sockets
- cast-in channels or dovetail devices.

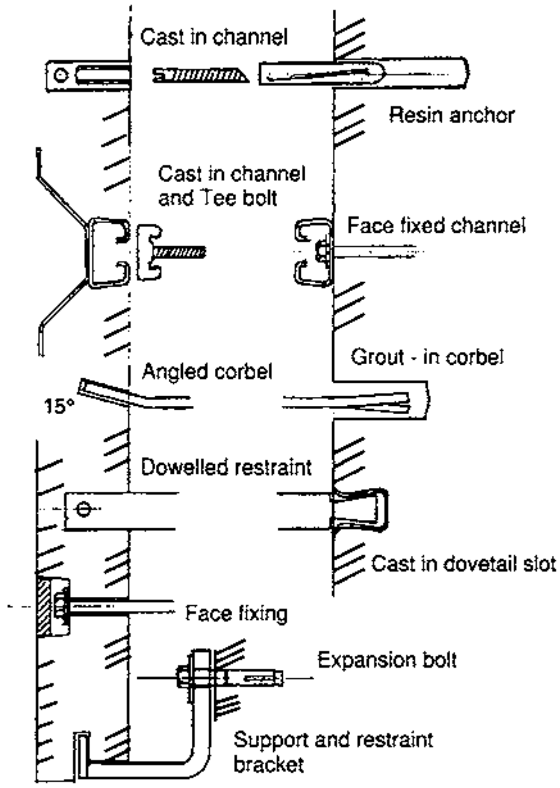


Fig. 7.13 Cladding attachment methods

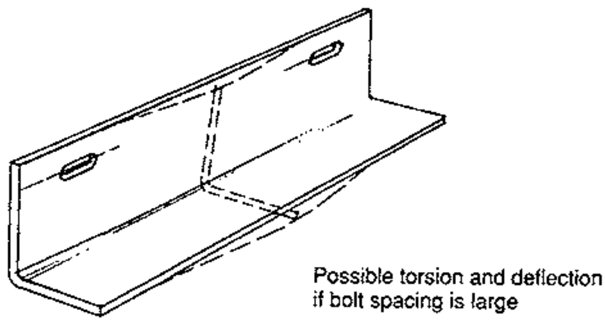


Fig. 7.14 Long angle design considerations

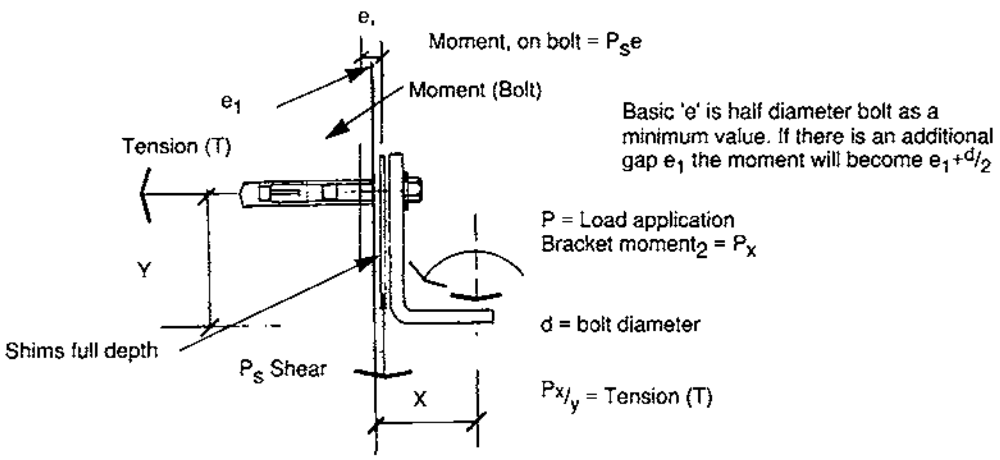


Fig. 7.15 Idealised design assumptions

Although, in the UK, limit state design has been increasing in its use, most fixing design is still calculated in permissible stress terms. The trend towards limit state philosophy will continue with the advent of Eurocodes.

Wherever possible, a fail-safe approach should be adopted with fixing design, i.e. more than one fixing should be used and fixings should be arranged so that, if one fails, the remaining fixings will still carry the load, albeit with a reduced factor of safety. This philosophy will, however, be difficult to apply in small cladding units, in which case the long term integrity of a single fixing will assume even greater significance.

It should also be remembered that any sudden failure of one fixing might induce a dynamic ingredient in transferred load to other fixings.

Safety must be of prime importance. Consideration must be given to bolt diameter and spacing, bracket size, etc. to obtain the most advantageous design to allow for variations in the strength of background materials. Idealised design assumptions currently used are shown in Fig. 7.15. The cost of providing additional fixings should, of course, be taken into account.

In the absence of any national standard, the assessment of safe loads on bolt fixings into concrete, masonry and other similar materials requires careful consideration. Bolt manufacturers may quote pull-out values from tests in ideal, laboratory conditions which are unlikely to be replicated on site. The engineer, therefore, should adopt a conservative view of such values. It is also necessary, where applicable, to consider the 'group' effect of clusters of bolts.

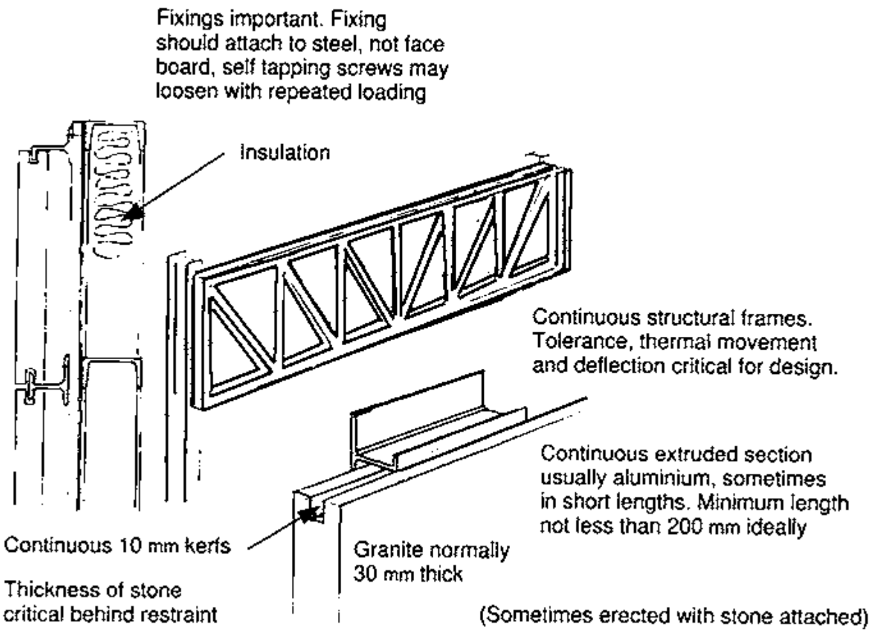


Fig. 7.16 General arrangement - stone truss system

It is becoming quite common in modem energy efficient buildings to provide large cavities and insulation. Such designs call for the use of sub-frames fixed back to the structure with the cladding fixed on the outer face. These sub-frames are generally acceptable if made from suitably protected standard mild steel sections. This method of support is also commonly used in overcladding situations adopted for renovation work.

The important points to be considered are:

- relative movements between the structure and the cladding
- deflections
- the stability of metal sections spanning between supports.

These methods are applicable largely to metal claddings but are also relevant to thin stone facings. It would not be normal to hang heavy precast units from such secondary frames.

An adaption of this type of construction in relation to thin stone cladding is used in what is known as 'stone truss' design. This method is used mainly in America and Scandinavian countries. Essentially it is a method of containing stone panels in a metal angle frame bolted back across an insulated cavity onto a steel truss spanning structurally between columns. There are structural advantages but design and construction difficulties are inherent in the methods adopted.

The stone facings are usually granite or marble with their thickness reduced to 30mm, or sometimes 20mm. These are below the required thicknesses called for in BS 8298.

Continuous grooves are cut in the stones leaving only thin sections of stone behind the retention angles. Often the angles are aluminium. There is a requirement to design the stone for flexural and shear strength and testing of a high level is essential in order to justify the designs. It should therefore be noted that any proposed designs of this nature need very careful consideration.

The claimed advantages of the method include the fact that the loads are supported off steel trusses, often a full storey height in depth, spanning between columns. This means that loads are carried straight back to the vertical supports and impose no loading on the floor edges. This may have particular significance in considering the earthquake performance of the structure and the likelihood of cladding becoming displaced.

The frames have to be designed to allow expansion movements at connections and also to be sufficiently stiff to limit deflection so as not to affect the cladding. Usually, the frames are faced on the cavity side with a building board and it is not unusual for the cladding restraints to be attached onto the board and not always into the steel frame member.

Self-tapping screws are often specified but these may loosen with repeated loading. More positive through bolts and cavity type expansion fixings should be considered in such situations.

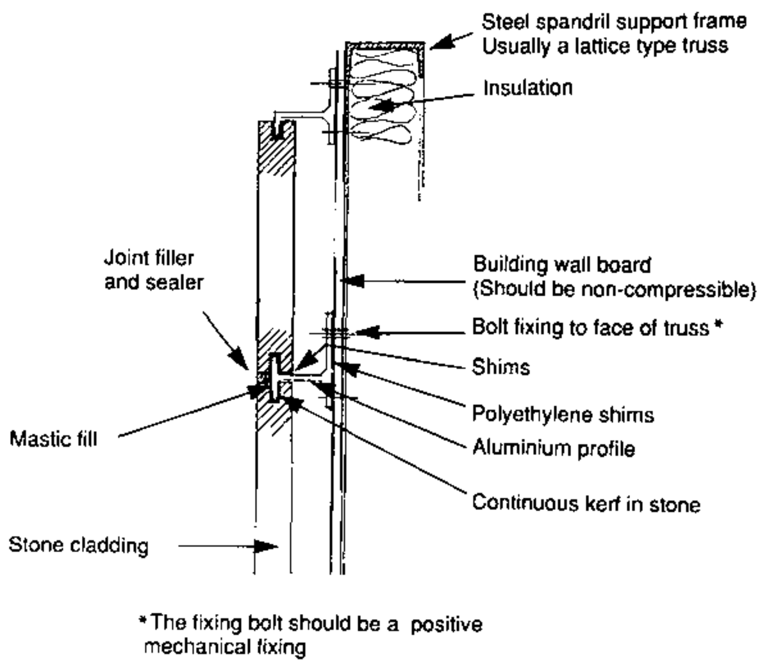


Fig. 7.17 Stone truss system details

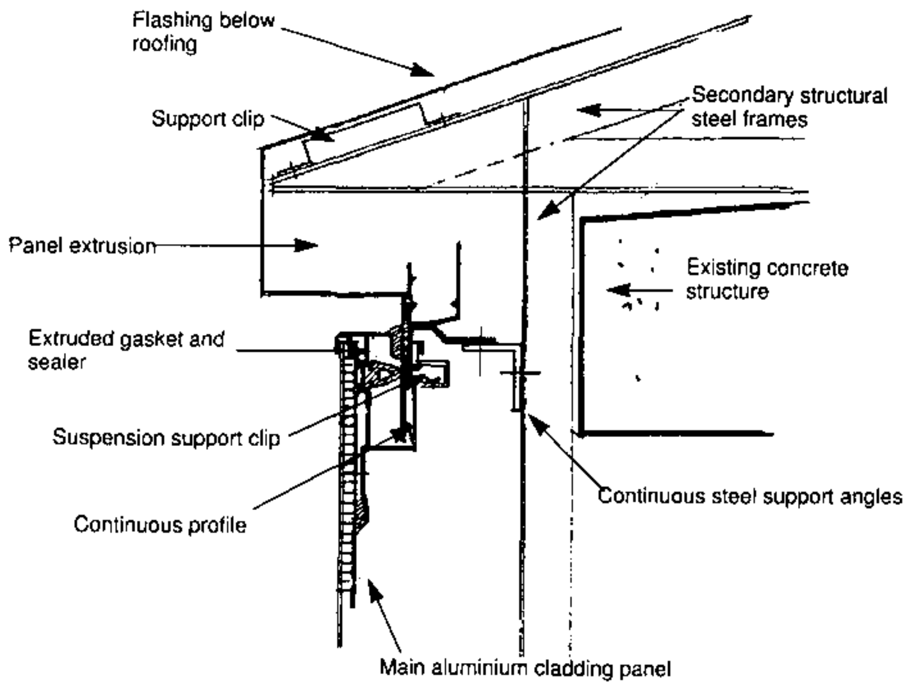


Fig. 7.18 Patent metal cladding

Metal cladding fixed to frames, as previously noted, can have very real tolerance problems and, thus, careful attention to detail is necessary if the construction is to work satisfactorily.

Factory made products comprising standard metal panels, frames and cleat fixings are manufactured to 'engineering tolerances.' Existing and new buildings will have constructional tolerances and inaccuracies of a greater order and the sub-frames will need to be sufficiently flexible to take up such tolerances and effectively match the factory product. The need for accurate surveying and setting out is important in such designs.

Movement has to be considered and, although the panel fixings allow independent movement within the fascia, building expansion joints must be recognised. Useful guidance is given in *Design of stainless steel fixings and ancillary components* published by the Steel Construction Institute.

7.10.5 Materials for fixing and fastening

The selection of materials, usually metals, to be used is dependent on several factors. These include:

- durability
- availability
- workability
- compatibility
- desired method of fabrication
- cost - this should be low on the order of priorities and should not be allowed to reduce the integrity of fixings.

The principal materials at present in use include:

- copper
- phosphor bronze
- aluminium alloys (see BS 8118)
- stainless steel (see BS 6105, grades 361,321 and 305 S15)
- protected mild steel - not generally recommended but used in industrial situations.

Further information on materials is given in Chapter 6. Materials commonly used for support (loadbearing) fixings include:

- phosphor bronze
- stainless steel
- aluminium alloys.

Materials commonly used for restraint fixings include:

- phosphor bronze
- stainless steel
- copper
- aluminium alloys.

In controlled applications, including combined support/restraint fixings, varieties of these metals may be used together. Protected mild steel might be used in industrial or farming applications or for buildings intended to have a short design life. It is also important that metals should be non-staining when used in direct contact with cladding material.

7.10.6 Fixing design considerations

These include:

- design life
- weight of cladding material
- additional applied dead loads
- loadbearing action of the units
- size
- method of location
- design characteristics of main structure, i.e. design strengths of materials
- location and spacing of main support elements
- deflections of structural elements
- fire
- extension of structure under thermal effects
- elastic compression
- creep
- position of expansion joints
- storey heights
- method of erection
- accessibility to locate fixings
- horizontal loads - panic forces, etc.
- wind speed and force factors
- special environmental conditions
- use of building
- any architectural requirements
- any planning constraints
- special material specifications
- contractual requirements
- programme requirements
- delivery requirements
- unloading restrictions
- use of plant and scaffold
- tolerances.

Angles, as single elements, are basically simple to design. The outstanding leg is designed as a cantilever section. The spacing of the bolts becomes important in long angles but does not cause problems in longitudinal bending. When using thinner angle sections, deflection and rotation at the toe should be checked.

7.10.7 Bolt and anchor design

Design

The design of bolts is the most important aspect of fixing design. The selection of a bolt type is difficult in view of the vast number of bolts available and due attention should be given to the basis of the allowable load figures provided by the manufacturers and the manner in which the figures have been derived.

The bolt generally accepted for use in concrete is the expansion bolt and this is acknowledged to be a cone action bolt in which a cone is drawn up, on tightening, into some form of split shell or ring.

Some bolts have a double action cone arrangement which theoretically pushes a split shell over two conical sections to give what is termed a 'parallel' expansion action. Such bolts are considered to have a higher load capacity and do in fact work quite well.

A smaller and less highly load efficient expanding shell bolt exists, but these are usually only available in the smaller diameters and suitable for use in good masonry and concrete. The under-reaming bolt is becoming more popular and is used more extensively in Europe. This bolt works on the basis of an expanding shell which is pushed out in a pre-cut under-ream hole and gives a combined expansion/tension resistance to pull-out within the substrate concrete.

Bolt types can be further classified into bolts which can be prepositioned with the fixing placed onto it and those which can be passed through the hole in the fixing, known as through bolts.

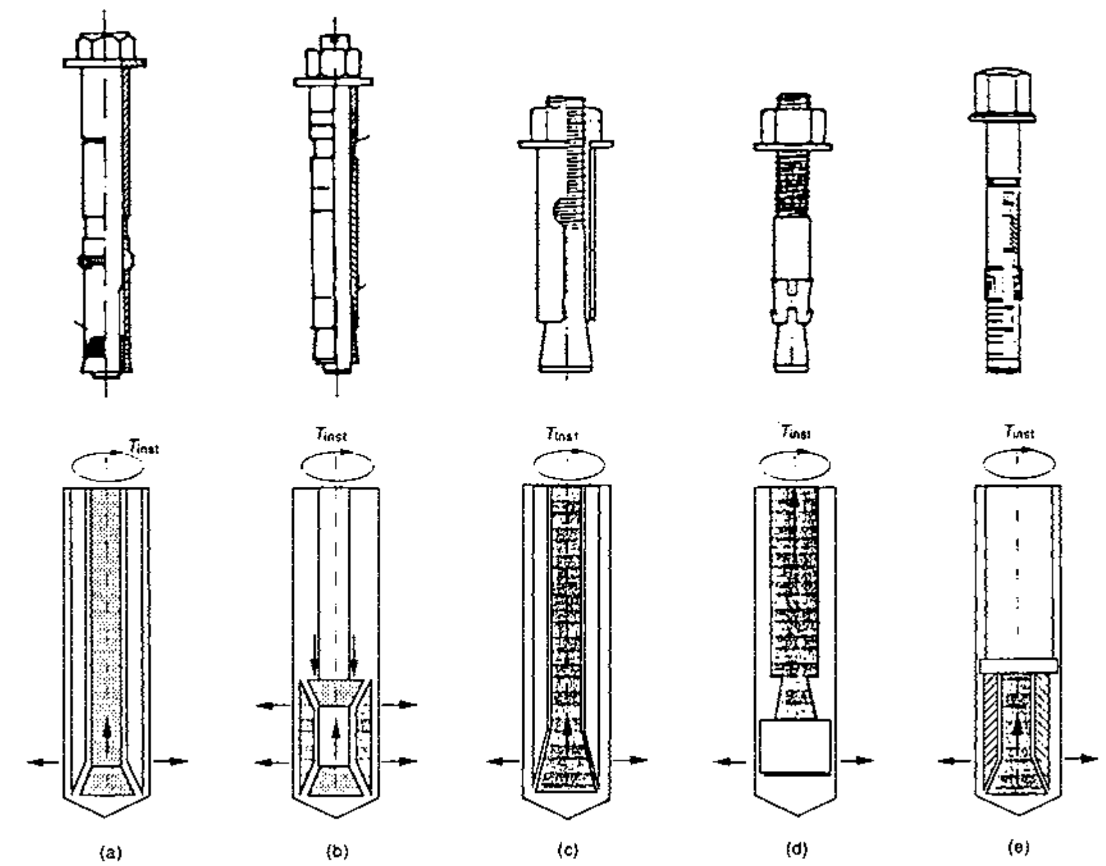


Fig. 7.19 Expansion mechanisms of various torque-controlled expansion anchors: (a) single-cone type; (b) double-cone type (c) taper-bolt type; (d) wedge type; (e) bolt with internally threaded cone. (Reproduced by kind permission of Comite Euro-Internationale du Beton/Thomas Telford Services Ltd. from the CEB report 'Fastening to concrete and masonry structures).')

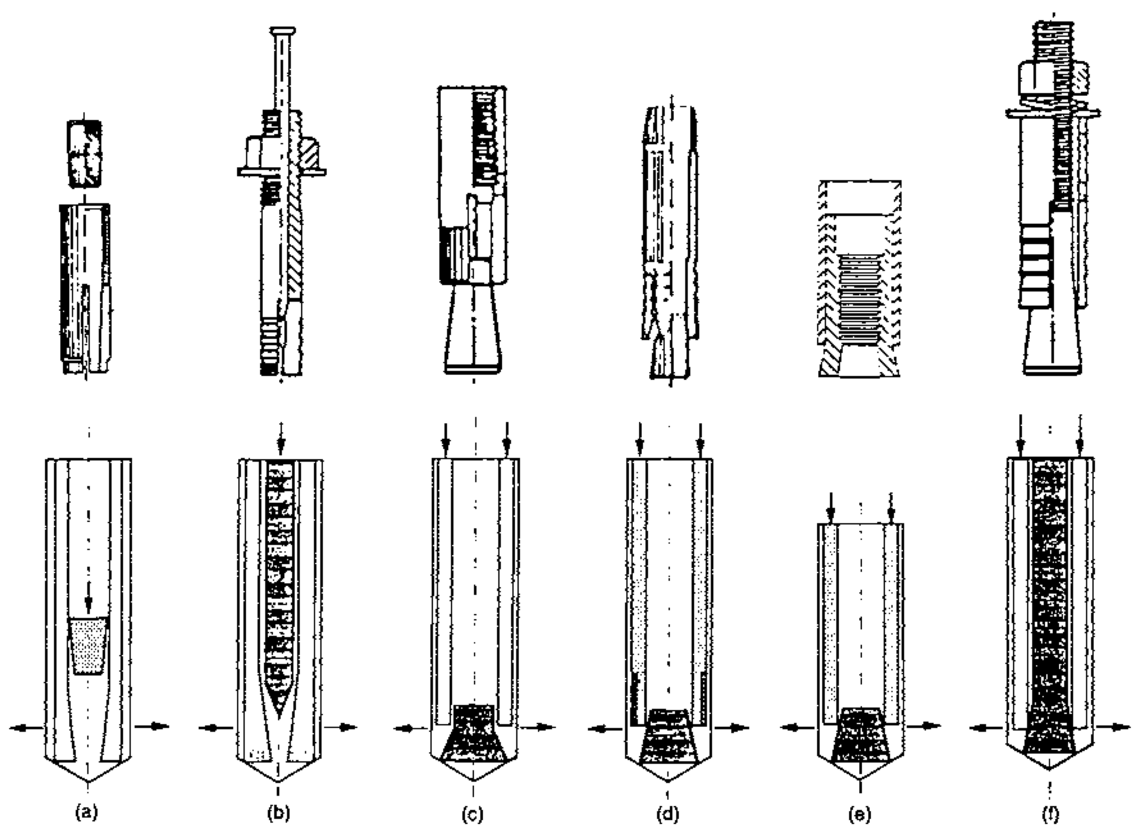


Fig. 7.20 Design and operation modes of metal deformation-controlled expansion anchors: (a) cone-down type ('drop-in anchor'); (b) shank-down type ('stub anchor'); (c) cone type; (d) cone type ('self-drill anchor'); (e) lead caulking anchor; (f) plug-bolt type. (Reproduced by kind permission of Comite Euro-Internationale du Beton/Thomas Telford Services Ltd. from the CEB report 'Fastening to concrete and masonry structures.')

Both types can have either a projected threaded stud or set screw. All these types are illustrated in Figs. 7.19 and 7.20.

In loadbearing situations, a bolt has a number of forces to resist. The downward load produces a shear force, the bending moment on the cladding support bracket produces a couple which imposes a tensile pull on the bolt and, in some circumstances, if there is a large amount of shimming, a moment stress in the bolt. Shear and tensile stresses can be combined to give a single resultant principal stress which is easily calculable. The value of the moment has to be determined by assessing a point within the concrete at which some sort of fixity can sensibly be assumed. The bolt then has to resist the combination of the principal stress and the calculated moment stress (see Fig. 7.15).

As a general guide, packing of about 10 - 15mm can normally be tolerated on a load carrying bolt, the diameter of which should ideally not be less than 10mm and preferably 12mm in high load situations. Smaller bolts are being more commonly used on the basis of cost but overall integrity and safety should be the primary concern. Load carrying bolts should have a minimum penetration of 75mm into sound concrete and 50mm penetration for restraint bolts.

When selecting a bolt on the basis of its safe shear and tension loads, care must be taken in comparing the values of various makes of bolt. All bolt manufacturers base their safe working loads on test results and although initial comparison indicates most reputab1e bolts of a particular type and diameter to be comparable in their specified working loads, the manner in which these working loads are derived from test results can vary.

The normal method of testing is based on the requirements of BS 5080 Parts 1&2 and the British Board of Agrement test procedures. Working loads are therefore based upon the results of these tests. Building Regulations Approved Document A paragraphs 2.9 to 2.14 deal with safe working shear and tensile loads for expanding bolt and resin bolted fixings.

Although a Factor of safety of 3 is considered by some to allow for variation in concrete strength, poor installation, etc., many checking consultants and authorities frequently call for the manufacturer's specified working load to be further reduced by a factor of between 2 and 3. This is completely arbitrary but is quite common. Relaxation of bolt prestress occurs fairly quickly and is noticeable within 24 hours. However, the loss of effective stress in the bolt can be caused over a much longer Period by creep in the base material. The Building Regulations Document Part A sections, referred to previously, require the design eccentricity to be increased by a minimum of half the bolt diameter to allow for possible edge spalling of the base material. This is an important additional requirement and can have a considerable effect on the required bolt diameter.

Two other important factors need to be considered in bolt design, namely:

- spacing of bolts relative to each other
- edge distance.

Expansion bolts obviously induce compressive stresses within the base material and an overlap of stress bulbs can occur when the bolts are too close. Reduction in load capacity must therefore be made.

Edge distance is critical and high stresses close to comers can cause complete failure of the backing material. There are various mathematical methods of determining suitable reduction factors. Most manufacturers give recommended spacing and edge distances based on test results.

Tightening of bolts

Having selected a bolt size, the next most important aspect of the installation is to apply the correct torque. A correctly calibrated tool should be used and such tools should be regularly checked. Torque produces a tensile stress in the shaft which is related to its length and diameter, the material properties of the base material and the diameter of the hole in the base material.

Stainless steel loses some of its stress over a 24 hour period and bolts should be checked after installation. Providing the applied load induces a stress which does not exceed the torque stress put into the bolt, there will be no slip. Once the load is exceeded, however, slip will occur and the fixing will be released. This may not cause distress if the difference is small but, nevertheless, in theory, a fixing has failed if slip has occurred. If the loading is increased after initial slip has occurred and further slip takes place, failure is effectively complete. It should be noted that the first slip figure should not exceed 0.1mm. Some bolt figures given by manufacturers do not fully conform to this requirement and great care must be taken on selecting a suitable working load.

A point to remember is that the tightening of bolts without the use of a torque wrench cannot guarantee correct installation: the majority of bolts under 12mm will be over-torqued and those above 12mm will invariably be under-torqued.

Sockets

Cast-in sockets without anchors are normally only used in light loadbearing situations and for restraint. The installation torque applied need only satisfy the working torque requirement. Cast-in sockets are normally only as safe as the backing material into which they are cast and particularly depend upon the way in which the socket is anchored.

Lifting sockets should be threaded over reinforcement bars. Location sockets should have cross pins which should always be set deeper into the body of the concrete than the outermost layer of reinforcement. The crosspins may sometimes be a hairpin bar projecting into the unit. The Same stipulation applies to cast-in channels. Any anchor bars or straps cast into the body of the material should be suitably inclined to provide pull-out resistance.

Resin-encapsulated fixings

Resin fixings are as strong as the resin and the action between the resin, bolt and parent material into which they are cast. It should be noted that the resistance between the backing material and a resin does not generally rely on bonding in the sense of adhesion and the pull-out strength comes from the roughness and fiction of the interface. The critical factors in the use of resin capsules are shelf life and installation procedures.

Installation

It is of extreme importance in the installation of any drilled-in fixing to check that the hole is of the correct diameter, is drilled straight and that all dust and debris is removed, preferably by the use of compressed air. This is because the most common form of installation difficulties encountered on site arise from incorrect drill hole size and the presence of the dust residue left from the drilling.

Expansion bolts should be lightly expanded by hand to just secure the cone before placing in the hole, but on no account should the bolt be hammered in position. Hammer-in sockets exist but these are not recommended for heavy duty fixings.

Brickwork, lightweight concrete and blockwork should not be relied upon for high integrity expansion fixings in loadbearing situations. Restraint anchors of lower load capacity may be used with care.

Resin anchors and grouted fixings can be suspect in any porous material and old brickwork where the resin or grout can be lost into voids. There are systems available to contain the resin or grout where porosity is hown to exist. One important limitation to be noted in the case of resin anchors is their vulnerability to fire. This type of fixing should not be used in relatively high load-bearing situations where there is the possibility of loss of strength and bonding in high temperature.

Expansion bolts should not be used in natural stone except for light restraint loads.

Positioning of fixings

Two important points should be noted when positioning fixings:

- they should be located so as to avoid rotation of the unit
- they should be designed so that, ideally, each fixing is equally loaded or at least designed to accommodate eccentricities.

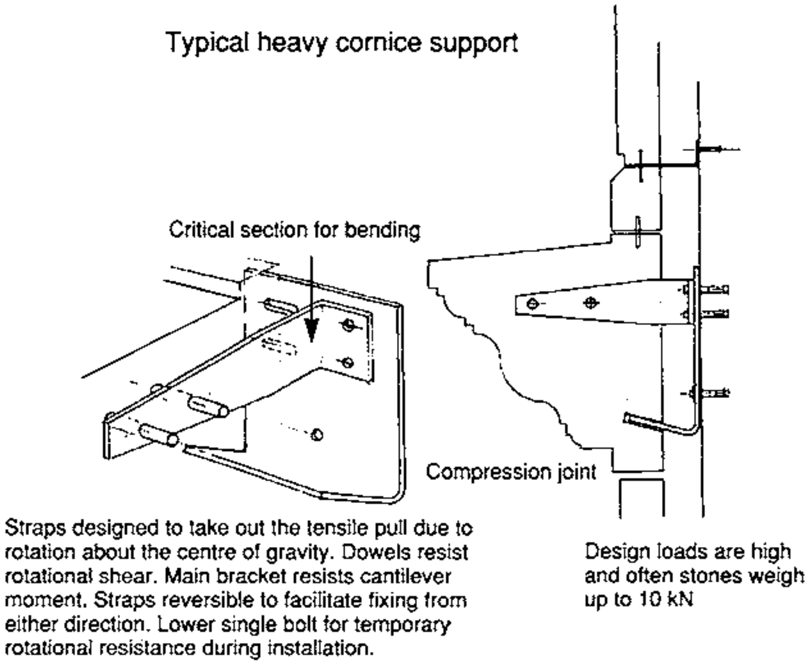


Fig. 7.21 Typical heavy cornice support

In all cases, the method of attachment must not cause overstress locally in the unit, fixing or structure under any combination of loading.

Supported units should not take bearing at more than two locations and uneven or unequal loadings should be avoided. Restraints should normally be Positioned at four Points and ideally should be equally loaded. It is sometimes desirable to use additional restraints on long panels, but consideration should be given to the likely deflection causing local overstress in the unit. It is not necessary to interlock one unit into another in large cladding units providing each is adequately restrained.

In smaller stone units, such as ashlar walling, it is desirable to lock the separate units together. This is easily achieved by dowel restraints into both stones. If stones are of small surface area, it is not essential to restrain every joint location back to the structure as independent dowels at alternate joints with restraints at the intermediate levels can be used. Thinner facings such as marble or granite can be treated in the same way except that the fixings are of lighter gauge material.

When designing a restraint system for stone facing, the four points of retention into each stone must be either in the bed joint or the vertical joints. It is not possible to use side fixings and horizontal fixings into the same stone as location in two directions cannot be achieved simultaneously. At any top or side course care must be taken to check that the fixing can be located into the stone. The most difficult fixing is the last one in a run of stones, especially if the stones are recessed behind a frame or brick & in. This fixing is often impossible to locate and is frequently omitted, leading to a local failure at an early future date. In some cases, where the loose fourth comer cannot be restrained, it is sometimes possible to use a dog cramp into an adjacent stone.

A fixing into the structure should always be positioned above the line of the cladding unit so that accurate positioning and adjustment can be accomplished. A fixing behind the unit cannot be easily adjusted nor can a stone be located unless loose dowels are used. Cornice stones require careful consideration and eccentric dead load moments must be adequate1y restrained (see Fig. 7.21).

It is sound policy to keep the number of components in a fixing to the minimum. Loose dowels, nuts and bolts, etc, although not always avoidable, do get lost or dropped off the scaffold. This is a potentially dangerous situation where fixings can be omitted or at the most only partially located.

Brickwork can be of two types:

- Complete outer facing skin
- Panel walls contained within a frame.

In the case of panel walls contained within a frame, compression joints should be provided at the heads of walls immediately beneath the structure and also down the side. The panel must be restrained by Some form of sliding anchor which must also provide the required degree ofrestraint. Usually there is a damp proof course at the base of such panels and restraint cannot be provided at this level. On no account should fixings puncture damp proofcourses.

When considering facing walls, due account must be made for movement both vertically and horizontally and the wall must be tied to the structure at the appropriate points as set out in the relevant British Standard Codes of Practice for the spacing of wall ties.

Parapet walls, in brickwork especially, are vulnerable to thermal movement and vertical joints must be provided at points close to the corners of the building, usually spaced at about 2m. If the backing wall is concrete, differential movement becomes critical between the two materials.

7.11 References and bibliography

Note: See Appendix B for a listing of full titles of British and European Standards referenced in the text. Some other relevant standards are also listed-

Roberts, J.J. et al.: *Concrete masonry designer's handbook.* Leatherhead: Eyre and Spottiswood, 1983.

Bradshaw, R.E., Buckton, G. and Southwick, S.W.: *Brick Cladding to Steel Framed Buildings.* Windsor; Redcar; Brick Development Association; and British Steel. (BDA Design Guide 18).

Mitchell's Advanced building construction and McKay's *Building construction volume 4,*

BS 6432: *Methods for determining properties of glass fibre reinforced cement material.* 1984.

Cem-Fil International Ltd. *Cem-Fil GRC Technical Data.* Newton-le-Willows, Merseyside: 1994?

GRC. Watford: Building Research Establishment, 1988. (BRE Digest 331).

BS 5950: *Structural use of steelwork in building, Part 6: Code of Practice for design of light gauge profiled steel sheeting. 1995*

CP 118: *The structural use of aluminium.* 1969

BS 8118: *Structural use of aluminium.*

Part 1: Code of practice for design. 1991

Part 2: Specification for materials, workmanship, and protection. 1991

External rendered finishes. Watford: Building Research Establishment, 1976. (BRE Digest 196).

BS 5534: *Slating and tiling.* Part 1: *Design.* 1978 (1985).

BS 5390: *Code of practice for stone masonry.* 1984

BS 8298: *Code of practice for design & installation of natural stone cladding & lining.* 1989

Estimating daylight in buildings. Watford: Building Research Station, 1963. (BRE Digest 41, second series).

Sunlight availability protractor. Watford: Building Research Establishment, 1975. (BRE report 12).

Anderson, J M and Gill, J R. *Rainscreen cladding: a guide to design principles and practice.* London: CIRIA; Butterworth, 1988.

Baddoo, N.R.: *Design of stainless steel fixings and ancillary components.* Ascot: Steel Construction Institute, 1993. (SCI Publication 119).

BS 6105: *Specification for corrosion-resistant stainless steel fasteners.*

Comité Euro-International du Beton. *Fastenings to reinforced concrete and masonry structures:* state-of-the-art report. London: Thomas Telford, 1994.

Tutt, J.N.: *Replacement ties in cavity walls - a guide to spacing and selection.* London: CIRIA. (Report 117).

British Board of Agrement MOAT No 19 1981 *The assessment of torque expanded anchor bolts when used in dense aggregate concrete.*

British Board of Agrement MOAT No 49 1992 *Technical guidance on anchors for use in cracked or non-cracked concrete*

Taylor, H P J.: *Precast concrete cladding.* London: Edward Arnold, 1992.

Owens, G. W. and Knowles, P. R.: *Steel designers 'manual.* 5th edition. Oxford: Blackwell Scientific, 1992. (SCI Publication 62.)

Pepperell, R.: *Stonemasonry detailing.* Builth Wells: Attic Books, 1990.

Steel Construction Institute. *Steelwork design guide to BS5950: part I: 1990: volume 1: section properties: member capacities.* 3rd edition. Ascot: SCI, 1992. (SCI Publication 202.)

Steel Construction Institute. *Steelwork design guide to BS5950: part 1: 1990: volume 2: worked examples.* Revised edition. Ascot: SCI, 1991. (SCI Publication 2.)

Steel Construction Institute. *Steelwork design guide to BS5950: volume 4: essential data for designers.* Ascot: SCI, 1991. (SCI Publication 70.)

Wilson, M. and Harrison, P.: *Appraisal and repair of claddings and fixings.* London: Thomas Telford, 1993.

Morton, J.: *Cladding steel frames with masonry.* New Steel Construction, 1994 vol2 no2 16-17.

British Steel Strip Products. *Enhanced peformance,* Newport? British Steel Strip Products, 1994.

Beeby, A. W.: *Fixings in Cracked Concrete.* London: CIRIA 1990. (CIRIA Techical Note 136.)

Construction Industry Research and Information Association. *Selection and use of fixings in concrete and masonry: interim update to CIRIA Guide 4.* London: CIRIA, 1991. (CIRIA Technical Note 137.)

Button, D. (Ed.) et al.: *Glass in buildings.* Oxford: Butterworth Architecture, 1993.

Centre for Window and Cladding Technology. *Standard and guide to good practice for curtain walling.* Bath: Centre for Window and Cladding Technology, 1993.

Doran, D. K. (Ed): *Construction Materials Reference Book.* Oxford: Butterworth-Heinemann, 1992.

Bull, J.W.: *The practical design of structural elements in aluminium.* Aldershot: Avebury Technical, 1994.

8 Repair and renovation

8.1 Introduction

8.1.1 Scope

This Chapter is about the structural aspects of the performance and treatment of existing cladding. Water penetration, insulation and appearance are not dealt with in detail in this report. Nevertheless, as mentioned in Chapter 2, many aspects of the performance of cladding may affect the future security of the cladding, or if inadequate in these respects, make the basic structure vulnerable.

Engineers appraising existing cladding will, therefore, be concerned with factors additional to matters of immediate structural adequacy. There is a wide range of types of cladding which an appraising engineer or surveyor may find. Clearly not all can be described in this chapter. However, most of the commoner types fall into one of the following five categories:

- external facing to masonry (loadbearing and non-loadbearing) (Section 8.2)
- cladding (all types) on traditional or iron frame (Section 8.3)
- masonry cladding (wet construction) on modem structural framing (Section 8.4)
- non-masonry cladding (mechanically fixed) on modern structural framing (Section 8.5)
- overcladding to cover existing forms of cladding (Section 8.6)

Of these, mechanically fixed or masonry cladding to modern structural framing - essentially the form of construction of the last 100 years - are most likely to be the forms requiring structural consideration. However, earlier cladding, sometimes historic, may also need attention. Table 8A summarises the characteristics and likely materials of each of these types of cladding, together with the dates when they were most popular, their structural characteristics and normal methods of fixing. It also gives references to the more detailed treatment later in this Chapter or elsewhere. Table 8A is thus provided as a quick guide to the relevant part of the report. In addition, checklists for appraisal are included at the end of each section.

The reasons for appraising, and possibly repairing, existing cladding vary considerably. Prior to the survey, there may be distinct evidence of damage or decay or the appraisal may be carried out as part of routine maintenance. In the latter case, repair or strengthening could be found necessary even without any symptoms of trouble being evident before the inspection. This Chapter therefore contains information useful to all parties inspecting cladding for whatever reason.

8.1.2 Appraisal of existing cladding

As with most structural elements, there needs to be a different approach to the appraisal and repair of cladding from that appropriate for the design of new construction. Whatever its age, the acceptance of any piece of cladding, or the need for remedial work to it, should be related more to its past, present and likely future performance than to current codes or to any preconceived idea of how it should be detailed today. Upgrading, especially in relation to insulation, may well be desirable in some cases while in others, especially historic structures, the maintenance of its original appearance may be of paramount importance.

The important point is that, except when working to a specifically limited brief, appraising engineers should not just respond to visually obvious faults in cladding. They should also consider potential problems, check whether these could be relevant to the structure being appraised and search for any signs of incipient distress.

Each case needs to be considered on its merits. The level of inspection in any particular case must depend on practical means of access. With tall buildings in particular, full access can be very expensive while, without it, vital clues to condition may be lost. Means of inspection may range from the use of simple binoculars, powerful telescopes, closed circuit television and abseiling, and even to the hire of hydraulic platforms and full scaffolding which provides the opportunity for. all parties to examine closely and probe surfaces and to take samples.

Generally the best method is to Start with simple means of access and to work upwards if the first findings point to the need for closer inspection and sampling. Sometimes the damage caused in opening-up may be so great, or the need for minimal interference *so* strong, that inspection has to be limited. In such cases, evidence from one or two inspection points may have to suffice, backed up by a broadly statistical assessment of how such construction behaves elsewhere. In such cases, it is particularly important to make sure that all parties understand the basis of any subsequent recommendations or actions.

Accurate dating and knowledge of what to expect from the work of any period can prove invaluable. The appraisal should therefore not be limited to purely visual inspection or physical testing, but should be backed up with a search wherever possible through the original designer's archives, contemporary journals and deposited plans in building control departments or information of any sort in local libraries or record offices. This applies as much to recent construction as it does to that of 19th century or earlier. A checklist on the appraisal and repair of masonry cladding on modern structural framing is included as Table 8C.

Additional comments on appraisal are given in sections 8.2-8.5 in relation to specific cladding forms. The Institution of Structural Engineers report *Appraisal of existing structures* also provides relevant advice.

8.1.3 Stages of repair and renovation

There may be several layers of separate components and fastenings between the structure and the outer surface of cladding which are provided so that the cladding as a whole performs adequately and, above all, safely. Repair or renovation of cladding, whether it be repair in-situ, part replacement, complete replacement or overcladding requires three stages of preparation, i.e.:

- investigation
- condition assessment
- specification, including re-design.

Information to assist in assessment and specification of repairs will be similar to that required for new construction. Repair or renovation can only be designed and specified with reasonable confidence of achieving practicality, efficiency and predictable cost after a thorough investigation has taken place. Original design drawings and specifications are of considerable help but physical inspection, sampling and measurement are generally a necessary part of investigation. It can rarely be assumed that a structure has been built absolutely as originally detailed.

If investigation requires expensive scaffold access, the assessment and decision making regarding the specification for repair may need to commence whilst the investigation proceeds. This is more likely to be the case when repair rather than

Table 8A Summary of cladding types

Cladding materials	Period of cladding use	Type of structure	Normal method of fixing	Structural action of cladding	Section number	Notes
Natural stone (hewn)	Any time in last 2000 years	Structural masonry walls	Cramps or interlock	None	8.2	Essentially craft processes but impinging on structural design due to differential movements.
Natural stone (wafer thin)			Bond			
Artificial stone & precast concrete			Cramps or interlock			
Rendering tiles and mosaic bonded slate			Bond			
Lead sheet			Lead dots			
Timber						
Brick & block						
Timber boarding	Any time in last 600 years	Traditional timber or iron framing	Mortices & pegs or nails	Spans between main framing timber	8.3	This section covers both medieval timber framing and its descendants and the full or partial iron framing of the period up to 1890-1900 as well as masonry facings of c. 1700-1800 or earlier timber construction
Brick or stone			Friction and bond	none		
Tile and slate hanging			Nails			
Welded sheeting of lead, copper or zinc			Nails, clips etc. on to backing of timber			
Metal, asbestos or composite sheetings	Mainly last 150 years		Bolts, hooks, clips, screws or proprietary	Spans between main framing members		
Natural stone Clay Brickwork Artificial reconstituted stone	Generally last 100 years	Modern structural framing	Ties, cramps and friction	Generally masonry spans between columns or floors. Subsididary framing sometimes used. Masonry, sometimes reinforced or prestressed to improve spanning capability	8.4	Modern framing is taken here to date from the introduction of structural steel framing and reinforced concrete about 1890-1910. Timber framed housing & schools etc. by period 1960 to present day are also considered modern
Calcium silicate brickwork Concrete brickwork Concrete blockwork	Generally last 60 years					
Metal, composite sheeting, metal asbestos, etc.	Mainly last 100 years	Modern structural framing (panel systems)	Bolts or hooks, screws or proprietary fixings	Generally span between structural framing members Subsidiary framing members are also used to reduce spans of cladding	8.5	Definition of modern framing as for 8.4 above
Welted metal sheeting on structural base concrete, metal, glass, polymeric and composites as panels or curtain wall components	Last 50 years					
GRP panels GRC panels	Last 30 years					
Generally metal (steel, aluminium etc.) but also GRP, GRC or composite	Last 20 years	Overcladding generally on modern structural framing including structural panel systems	Bolts, screws on proprietary sub-frame	Cladding and its sub-frame spans between structural framing independently of existing cladding	8.6	Original cladding remains but is protected from rain and wind by the overcladding. This is both a remedial system and one itself needing appraisal.

recladding is to be carried out. Such a work pattern requires continuous supervision where fixings are concerned.

If the evidence suggests that cladding replacement may be required, then the survey should record information which would assist in defining the practicality of unbolting or cutting fastenings. At the same time, the practical means of making crane attachments to existing cladding and handling away the existing cladding should be considered.

Although the prime objective of the investigation might be cladding, the condition of the structural frame, e.g. steel, concrete or timber, etc. should be confirmed by examination, testing in-situ or by sampling.

Where it is decided that it is desirable to overclad or repair, the existing cladding must be assessed, not only with regard to its existing conditions, but also for:

- its future longevity
- compatibility with new materials or repair materials.
- its likely long term reaction to exposure to a new environment created by overcladding.

After the structural investigation and assessment, the repair to existing materials or fixings or the recladding or overcladding of the building, either in part or in its entirety, can be specified. There might well be several options for a design team to discuss with the client. These will range from local or complete upgrading of the existing cladding to recladding with curtain walling, overcladding or rainscreen cladding.

8.1.4 Internal forces on cladding and related structural elements

Differential movements due to changes in temperature and moisture produce internal forces which need to be taken into account in cladding repair, renovation or replacement. Fortunately, in most cases where cladding is coming up for appraisal, the major initia1 movements due to drying shrinkage or moisture expansion will have taken place. However, the possibility of such movements should not be forgotten. Diurnal and seasonal variations of temperature or humidity must certainly be considered as forces to be resisted or, alternatively, as movement to be allowed without restraint. All engineers carrying out appraisals of existing cladding should be familiar with CIRIA Technical Note 107 *Design for movement in buildings.*

One of the most difficult problems with cladding is not its adequacy to withstand the forces which it is designed to resist, but the effect of the unintended transfer to it of forces intended to be carried by the frame or other independent structure. This may be due to inadequate tolerances, lack of thought in design or simply bad workmanship. Further, not only can it damage the cladding, but it may transfer loads onto the frame in ways which the members of the frame cannot resist without damage.

8.1.5 Assessment of damage to cladding by fire and its repair

Unless the extent of the damage is such that the need for replacement is obvious, the cladding of fire damaged buildings should always be closely inspected. Particular attention must be paid to the boundaries of damaged areas bearing in mind suitable criteria for deciding the extent of necessary replacement. Indicators such as the charring of timber or the distortion of metal sheeting, curtain walling or the damage to protective coatings can indicate the limits of necessary renewal.

Other materials such as natural or reconstituted stone, brickwork or concrete blockwork may be less susceptible to direct damage from fire but cracking, spalling or bowing may have been caused by distortion of the building structure. In such cases, as long as the future stability of the frame has not been impaired by the fire, its affected parts may be made good. The damage may be largely confined to cladding components such as insulation, damp proof courses or mastic joints. Nevertheless, the need for inspection is likely to be just as great. The danger from spalled surfaces is discussed below.

Whatever the type of cladding, it is particularly important to inspect cavities, especially behind dry linings to make sure that fire-breaks, thermal insulation and waterproofing are still intact and that all fixings are undamaged.

Resin anchors to concrete could well be weakened by fire yet appear serviceable. It would be prudent to apply loading tests to sample fixings where the security of cladding panels depends on these. Similarly, resin ties between the skins of masonry panels could be affected by heat. Insulation in cavities can be destroyed by fire or lose its effectiveness through heat. Such an effect on the insulation within concrete sandwich panels could also affect the integrity of the outer leaf.

One of the most important points to consider in inspection is the danger of rendering or of the surface of brick, concrete or stone being loosened by heat. Tapping to detect any hollow sounds is the simplest and, in most cases, the best method of checking loose surfaces.

Where there is steel reinforcement in concrete cladding, it is worth checking whether rusting could also be contributing to any loosening Of the surface material. Additional information regarding the loading aspects of fire are included in section 5.6. All cracking, including that not immediately apparent, may in the longer term lead to deterioration and/or corrosion. Useful information on the assessment and repair is given in Concrete Society Report No 15.

8.2 External facing to masonry (loadbearing and non-loadbearing)

8.2.1 Scope

This section deals with the use of applied or mechanically fixed cladding to masonry walls. The backing material will vary. Where render, etc. is applied to masonry infill of framed buildings, careful detailing of junctions between frame and other material is required.

Failures in natural stone and reconstituted stone cladding tend to be largely related to fixing methods and fixing materials, whereas the failures of other applied materials tend to be largely caused by incorrect mixes, methods of application or, more generally, themal and moisture movement.

The principal materials used for facing loadbearing or non-loadbearing masonry walls are considered in the following paragraph and in Table 8B.

8.2.2 Natural stone

In some cases natural stone is applied as a thin facing by means of mortar, resins or adhesives to a solid backing wall. Defects to this type of facing are similar to those mentioned in section 8.2.5.

The more common use of natural stone is as a thicker, i.e. more than 40mm face thickness. This needs to be supported vertically and restrained horizontally. The susceptability to corrosion of all metals used for fixings and supports should be checked (see Chapter 6). Nowadays fixings and supports are always of non-ferrous materials. There can even be difficulties here if the wrong type of metal is used. Stone selected for cladding is generally unaffected by the environment except at its external surface. Cleaning processes are often more damaging than the contamination that they remove.

Generally, however, defects are caused by rusting and corrosion of ferrous fixings. Some local repairs can be carried out, depending on the extent of corrosion, but major replacement of the fixings is inevitably required in the long term. This means that the whole of the facade has to be removed. To comply with modem Codes of Practice, etc. it may then also be generally necessary to increase the size and frequency of fixings and to cut joints.

Some local repairs can be carried out using reconstituted stone mortar, sometimes known as plastic stone. Reinforcement may need to be introduced depending on the size of the area to be replaced with the reconstituted stone. Patch repairs using materials as close to the original as possible will have the best chance of being inconspicuous. A polymeric ingredient in repair mortar may well cause differential wetting and drying and thus cause ageing effects to be more visible later.

8.2.3 Reconstituted stone & stone-faced concrete

Reconstituted stone is used less frequently than natural stone. Composite panels of concrete with a stone facing are, however, used more frequently in modem cladding construction.

The most common problem with reconstituted stone is associated with the panels used in the 1950s and 1960s. These used a fairly weak concrete generally with minimal cover to ferrous reinforcement. Poor detailing for weathering and permeation of the mix allows corrosion of reinforcing causing spalling of the face. The same durability considerations apply to reinforced reconstituted stone as to precast concrete generally. This is dealt with in Chapter 7. Some local repair by cutting out and epoxy replacement can be used, but again this may produce relatively short term results.

It has been fashionable in recent years to carry out stone cleaning by a variety of methods. Even those techniques avoiding chemicals and employing a 'gentle wash' can still be harmful to the stone. They can give rise to residual staining and remove the natural coating to the stone, the moulded detailing and can indeed accelerate erosion.

Table 8b Natural stone as an external facing to masonry

Defect	Possible cause	Appraisal method	Repair method
1. Cracking of stones and joints	Movement of structure, settlement of attachment of stones to structures or each other see also (2) below	A visual inspection possibly limited opening up	Depending on the seventy of the defect, local stones can be cut out and replaced. Also additional fixings can be provided by drilling through the stone (taking out a core first), fixing with non-ferrous bolts or resin anchors and replacing the core as a plug on the surface.
2. Spalling, splitting, lifting	Volume increase of corrosion in embedded iron on steel cramps, etc.	Inspection and checking of fixings, quality, positioning and strength	As above, plus replacement fixings. All of these methods can only be applied if the basic fixings are adequate, are not corroding etc. If rusting is occurring, this will continue and the only method is to replace the stones with non-ferrous fixings.
3. Staining decay	Inadequate protection at parpet details, etc.	Inspection through small holes to view fixings and condition at rear stone (where a cavity exists) by inspection instruments such as endoscopes etc	Some local repairs with 'plastic stone' can deal with minor defects, weathering
4. Cracking and decay at joints	Hard mortar in joints has prevented movement	Where thin skins bonded to backing, hammer test and other inspection methods as per render (see later)	
5. Accelerated decay	Poor selection of stone type e.g. sandstone in inappropriate exposure	Visual inspection	Some local stone based mortar repairs possible, otherwise major replacement.

8.2.4 Sand and cement renders together with traditional oil mastics and roman cements

Defects which arise for all of these types of face-applied finishes generally relate to:

- insufficient key
- contamination from backing, e.g. by salts
- finishing coats stronger than backing
- thermal movement
- frost action caused by shrinkage cracking allowing moisture penetration.

Some local repairs can be carried out over a considerable period of time but if the defects are serious, then major replacement is inevitably necessary.

8.2.4 Tilings, mosaics, etc.

These finishes are used less frequently in current construction methods. Where they are, as for artificial stone facings to concrete panels, they generally form an integral part of the casting process.

The problems which generally existed in the 1950s and 1960s type of construction were due to incomplete adhesion. Having no mechanical restraint, they have frequently been dislodged through insufficient allowance for movement between panels and insufficient allowance for the shortening of stressed concrete due to creep.

Poor detailing at heads and parapets, cills, etc. also allowed moisture to enter between the facing and the concrete causing deterioration of adhesives, etc.

8.2.6 Lead sheet

This is rarely used on its own and generally tends to be attached to some other form of backing such as boarding. Lead coated steel sheeting can be applied to masonry or other backing structure.

The causes of defects to lead sheathing are simply due to fixings and size of sheet, etc. It is not a good material hung vertically although it can sustain relatively steep angles provided that fixings, sheet sizing and the allowance for expansion movement are adequate.

8.2.7 Asbestos

Corrugated asbestos was used for very many years as an external cladding material. Plain sheets were also used, mainly as an inner lining. Where it is necessary to disturb this material, it should only be handled while observing the precautions of the Health and Safety Executive.

Substitutes for asbestos are available and should always be used in repair and renovation works.

Table 8C Reconstituted stone as an external facing to masonry

Defect	Possible cause	Appraisal method	Repair method
1. Cracking of stones and joints	Movement of structure, settlement of attachment of stones to structures or each other. (see also (2) below)	Visual inspection	Some local cutting out and repair with resin can be carried out. These are only of limited effect for a relatively short period. Otherwise overcladding, possibly coating with impervious material or alternatively complete replacement of panels.
2. Spalling, etc.	If reinforced, due to permeability of 'stone' or insufficient cover and or quality (see chapter 6)	Use of cover meter Visual and possibly internal inspections as for natural stone	
3. Surface deterioration	Incorrect mix	Visual inspection	

Defect	Cause	Appraisal method	Repair method
Crazing	Insufficient key	Visual inpsection. Hammer test. Damp meter internally. Material testing.	Some local repair possible depending on extent of defects but generally large areas need complete renewal, including treatment of backing material if required.
Cracking	Differntial strength coats		
Delamination	Contamination from backing Salt action (Gypsum and Portand Cement sulphate attack with expansion) Frost action Movement (Wind on structure, ground, thermal, vibration) Incorrect mix Unsuitable aggregate to mix Incompatible backing Coats too thick		

Defect	Possible cause	Appraisal method	Repair method
Cracking Loose spalling	Absence of movement joints or possible inadequate spacing of same. Failure of adhesive if used	Visual inspection. Hammer test. Damp meter internally. Material testing.	Local repair, but likelihood of continued movement. Complete removal and reinstatement of finish. Movement joints necessary if continued movement of background expected. Storey height horizontally, 3m vertically.

8.3 Cladding (all types) on traditional timber or historic iron framing

8.3.1 Types of cladding

Cladding of a wide variety of types has been applied to traditional timber framing over several centuries. Such cladding is sometimes traditional timber boarding, sometimes modern sheet material, sometimes brick or wattle and daub infill and sometimes elegantly detailed stone facings which make the are found of 'geometric tiling,' an expression for tile-hung cladding designed to look like loadbearing brickwork.

8.3.2 The problems, their analysis and cure

The most likely problems with these types of cladding are:

- decay or distortion of the cladding material
- failure of battens or other subsidiary structure
- failure of fixings.

These groups of problems are best considered separately but identification, analysis and cure should be dealt with together in each case. It is always desirable to inspect existing cladding from both sides, even if this entails cutting through plaster or drilling inspection holes. With masonry facings added to old timber framed buildings, it is difficult to draw general conclusions. Nevertheless, some broad guidance on this is given later in this section.

Very few iron framed structures exist but those which may be subject to investigation might be expected to have been clad in the range of materials used on timber frames. The approach to repair of cladding on iron frames will therefore, in many ways, be similar to that of timber framed cladding. Techniques for cladding removal and fixing specifications may however be

With simple sheet materials like corrugated or profiled iron, steel, aluminium or asbestos the defects are usually plain to see. In most cases either the sheeting is acceptable or replacement is necessary. Patching or separate sheet replacement is possible but laps are disturbed and old materials are difficult to reseal. This is very much a second-best solution.

With sandwich or laminated materials, the problem of assessing the integrity of the units becomes much more complicated. A first check may be simply to tap the surface or shine an oblique light to identify corrugations or other irregularities but it may be necessary to drill holes for inspection or use ultrasonic or other non-destructive testing.

Rot is not always easy to detect with timber boarding which has been painted. Soft spots on longitudinal depressions in the paint surface which also feel spongy are a fairly clear indication of rot. Tapping with a sharp spike gives a good indication of soundness but this will break the paint skin and should normally be used only where repainting is going to. be necessary. If the inside of timber cladding is not exposed to view, it is particularly important to check whether there are any signs of dry rot in the cavity. One of the major advantages of timber boarding is the ease with which rotted or split boards can be replaced without disturbing the whole wall.

With clay or slate cladding, the most likely cause of failure is not the cladding material itself but the fixing nails, pegs or the battens. These are dealt with in the following sections. Nevertheless, frost damage to clay tiles is not out of the question and slate is prone to decay in the long term. Replacement is usually the only solution in both cases.

Table 8F Lead sheet

Defect	Cause	Appraisal method	Repair method
Corrosion Fatigure Creep Fixing failure	Oversized sheets for weight of lead Overfixing (too many) Acid attack electrolytic action (contact with incompatible materials) Previous faulty repairs condensation under roof sheets Inadequate provision for expansion. Lack of lead 'dots' for fixing	Visual inspection. Assessment of sizing Standard of fixings Ventilation Atmospheric conditions	In accordance with LDA recommendations. Lead bearing replacement material. Patination oil to prevent weathering. Remove incompatible materials; some metals, particularly aluminium in a marine environment. Avoid dilute solution of organic acid leach from hardwoods.

Failure of battens or subsidiary structure
Timber studding or battens to which boarding or sheeting is fixed may well be a greater source of trouble than the actual cladding material. Studding is particularly subject to dry rot in enclosed situations and to wet rot where the cladding has failed. Further, the danger from the failure of battens or studding can be much greater than that of the cladding. It is therefore important to check the conditions within any enclosed space from the point of view of possible deterioration of both the cladding material and the battens or rails.

Failure of fixings
Failure of fixings is the most likely cause of trouble with cladding to traditional timber frames. This applies to fixings to the cladding or between any subsidiary studding or battens and the main structure.

Nails are particularly vulnerable to corrosion and this is difficult to examine without removing representative nails. With timber boarding or sheet materials as cladding, there may come a time when it may be cheaper to add extra fixing nails than to pursue the investigation of the adequacy of the existing ones. Wrought iron nails generally remain sound in conditions which would corrode steel nails. Therefore, if existing wrought iron nails are able to continue to contribute to the fixing, then they should be retained. There is therefore a case for looking at each situation individually. Random extra nailing can look very untidy.

Woodscrews tend to have a longer life than nails, but when replacing them it is worth considering whether the condition of the other materials is good enough to justify the extra cost of stainless steel or non-ferrous screws. Also with nailing, whether to boarding, battens, tiles or slates, it will generally be more economical in the long term to use galvanised nails rather than plain wire ones. There is the further advantage that galvanised nails and other fixings reduce staining, especially with painted timber boarding.

Bolted fixings to steel or iron angles or other secondary framing need to be inspected carefully. Even if these look sound and well painted, they will sometimes be found to have been fractured by the expansion of oxide between the steel members joined with the bolt head or nut still held in place by the paint. A spanner is a good simple tool for checking on this possible defect.

The cladding of timber or iron frameworks in recent years may have been fixedy shot-firing. This is only effective when the background material is suitable and sound with the work being carried out by a skilled operator.

Masonry facings to earlier timber framing
Many 17th and 18th century houses with elegant brick or stone facades are really earlier timber-framed buildings given a face-lift to suit changing fashions or as an indication of prosperity. Frequently, this brick or stone is no more than just cladding although it may look like loadbearing construction. The fixing of such masonry was frequently poor and, with the effects of water and frost, the outer skin often pulls away from the original framing. Stainless steel rods fixed in resin will often be the best remedial ties and fixings and, if the work is carried out well, these ties are virtually invisible. However, conditions and details in actual buildings vary so much that the only safe advice is to check what is there carefully and act according to what is found. Above all, one should not jump to quick conclusions about what looks like loadbearing masonry as this may not always be the case.

8.4 Masonry cladding on modern structural framing

8.4.1 General
This section is about problems with the use of 'masonry,' in the broadest sense of the word, applied as cladding to structural frames, generally of structural steel or reinforced concrete but sometimes of timber panel construction. The most likely masonry cladding materials, or combinations of materials, are listed in Table 8A. 'Modem structural framing' has evolved since just before 1900. Fig. 8.1 illustrates typical details for masonry cladding to a reinforced concrete structure. Such details have been used since the 1950s and the compressible layer was often omitted.

Of the problems which may be found with masonry cladding, whether visible or not, the following are the most likely:

- inaccuracy of structural frame
- movement of structural frame
- movement due to thermal and moisture effects
- corrosion of steel or iron
- inadequate spanning capacity
- inadequate fixings or insufficient width supporting ribs or ledges
- decay of masonry.

A check list for appraisal of some of these problems is given in Table 8G.

8.4.2 Damage due to movement of structural frame

The problem
Before tackling cracks, spalling, bulging or other defects due to movement, it is important to distinguish between a wide variety of causes. Table 8H lists some of the most common movements. Most of these defects are due, at least in part, to movements of the structural frame. Frequently, more than one movement is combined. The most important point for the appraising engineer to note is the time when these movements occurred.

Most of the elastic movement, certainly that due to self-weight, (a, b & c, Table 8H) will have taken place before the building is used. This is also because real live loads, as distinct from the imposed loads required by codes, will largely be a small proportion of the total.

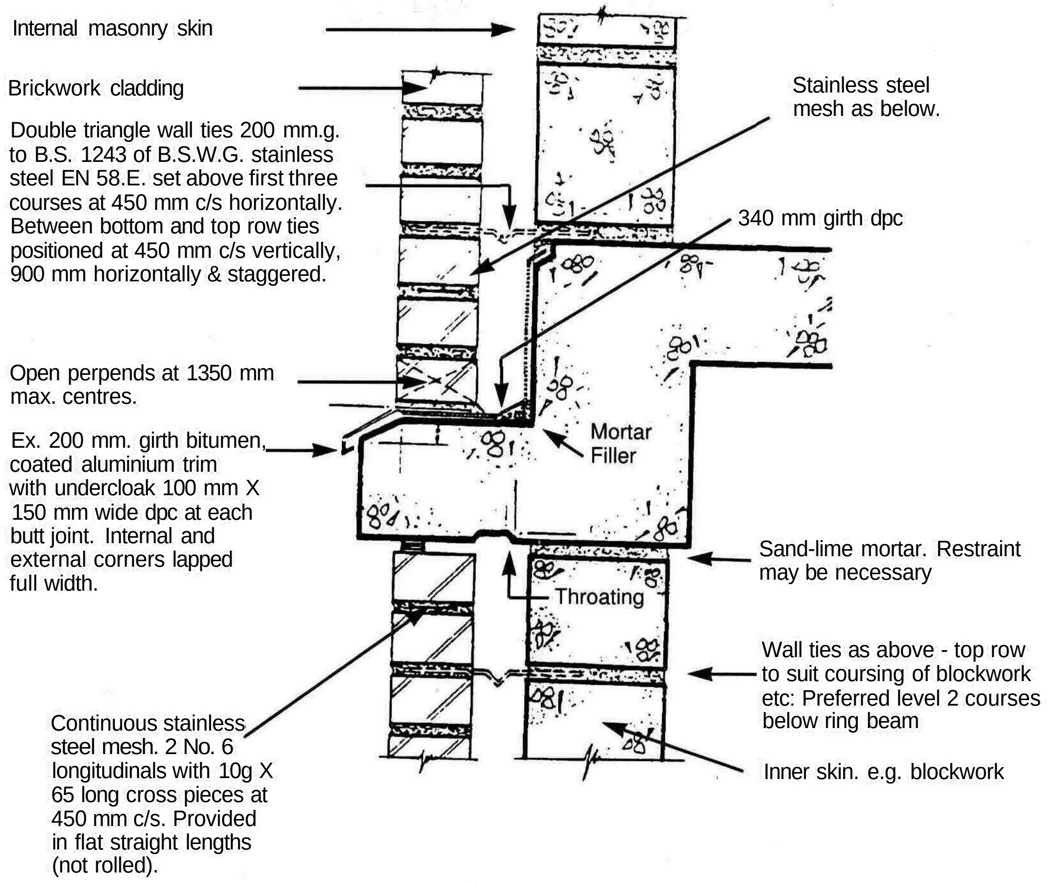
Movements (d) to (i) inclusive listed in Table 8H are medium term which for the most part are irreversible. In theory they can go on to a minute degree almost indefinitely but the rate of movement in each case falls off so rapidly that, by the time building appraisals are likely to be carried out, they should have decreased to a negligible level, although the results of earlier movement may remain. In such cases all that is usually needed is to repair the damage without taking any special precautions to prevent repetition. Nevertheless it is necessary to be reasonably sure that a state of stability has been reached. This is discussed further in section 8.4.6.

If the building has been in use for several years before any defects such as cracking or spalling appear, or if they recur after initial repairs, these are most likely to be due to movements (j) (k) or (1) in Table 8H.

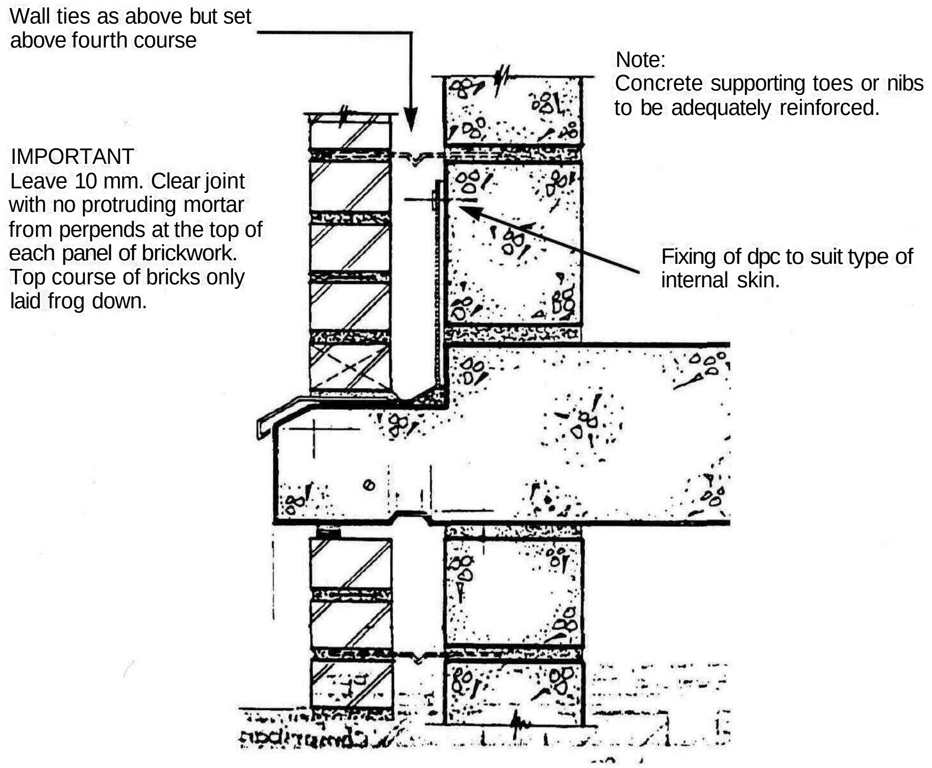
Racking of the frame in wind can lead to diagonal cracking and local spalling of the masonry, especially at its edges. Overall expansion or contraction of the structure due to changes of temperature may also cause diagonal cracking and spalling. The main clue is in the timing of cycles of opening and closing, the damage occurring at seemingly random intervals in the case of racking and seasonally with temperature changes.

Foundation movement - other than that due to initial consolidation under load - is another cause of mainly diagonal cracking to masonry cladding and can occur at any stage in the life of a building. A reliable explanation should be diligently sought and can nearly always be found. In cohesive soils, the planting, maturing or cutting down of trees are possible causes, as are increases in traffic alongside, adjacent new construction, leaking drains or a change in water table.

Appraisal
Obviously it must be up to the appraising engineer to decide what is adequate. There is no need to make a hasty condemnation merely because the first check is not encouraging. This is particularly important with masonry cladding panels because simple strengthening of the panels is seldom practicable or indeed possible. Uncertainty, once expressed, can easily lead to large scale demolition. Thus, the decision to reject masonry



(a) Downstand beam with supporting Toe



(b) Extended slab

Fig. 8.1 Typical masonry cladding to a reinforced concrete framed structure

Table 8G Checklist of possible problems in the appraisal of masonry cladding

Possible problems	Likely symptoms of distress in cladding	Likely causes of problems
Movement of structural frame	Cracking Spalling and bulging Falling slip bricks, tiles, etc.	Insufficient bracing Foundation settlement Shrinking of concrete Creep of concrete Changing temperatures Elastic deformation
Movement due to thermal and moisture effects	Cracking Spalling and bulging Falling slip bricks, tiles, etc. Horizontal displacement Cracking at returns	Lack of adequate restraint to prevent movement or real freedom to move (see above also)
Errosion of steel (or iron)	Cracking of masonry at location of steel (or iron)	Inadequate cover or protection to steel (or iron)
Inadequate spanning capacity	Cracking Bulging Failure of joints	Excessive movement
Inadequate fixings Insufficient width of supporting ribs or ledges	Probably none, but possibly disturbances of cladding just above supports	Poor workmanship Insufficient tolerances allowed in the design
Decay of masonry	Cracking Spalling Bulging of units Monitor deterioration	Water absorption Freezing Chemical attack Inappropriate materials , e.g. Mundic)

cladding solely on grounds of uncertain lateral strength should not be taken lightly. However, if doubts persist, a substantial increase in effective spanning capacity is often possible, with little disruption, by improving the edge fixings so as to give a more advantageous set of support conditions, especially in relation to arching. This is discussed in section 8.4.6.

Treatment of defects due to frame movement

If the defects in the masonry cladding are found to be caused by the racking of the frame in wind or by cyclic thermal movements, the most obvious choice for a cure is between safely loosening or separating the cladding, so that the frame can move slightly without transferring any forces to the cladding, or stiffening the structure. However, there is a third option, although seemingly a more difficult one, and that is to design the cladding and its connections to the frame so that they together resist or absorb the movement. The details of such measures are beyond the scope of this report but is should be remembered that actions to improve free movement can reduce overall robustness and may in themselves lead to new problems unless carefully thought out.

With foundation movements occurring well after any initial consolidation, the best solution must be to seek the cause, monitor the movement for as long as practicable and then cure the problem, for example, by repairing a leaking drain.

Where this is not possible, there are the options of underpinning, piling or using a geotechnical injection to limit future movement. These solutions should be the last resort. If, for instance, the trouble has been caused by adjacent building work, the effects of this may have largely ceased by the time the appraisal takes place. (See also the IStructE Report *Subsidence of low rise buildings.)*

Each case is best considered individually, always bearing in mind that the money spent on a reasonably full investigation is likely to be better spent than on a hasty repair based on conjectural analysis.

8.4.3 Moisture and thermal movements

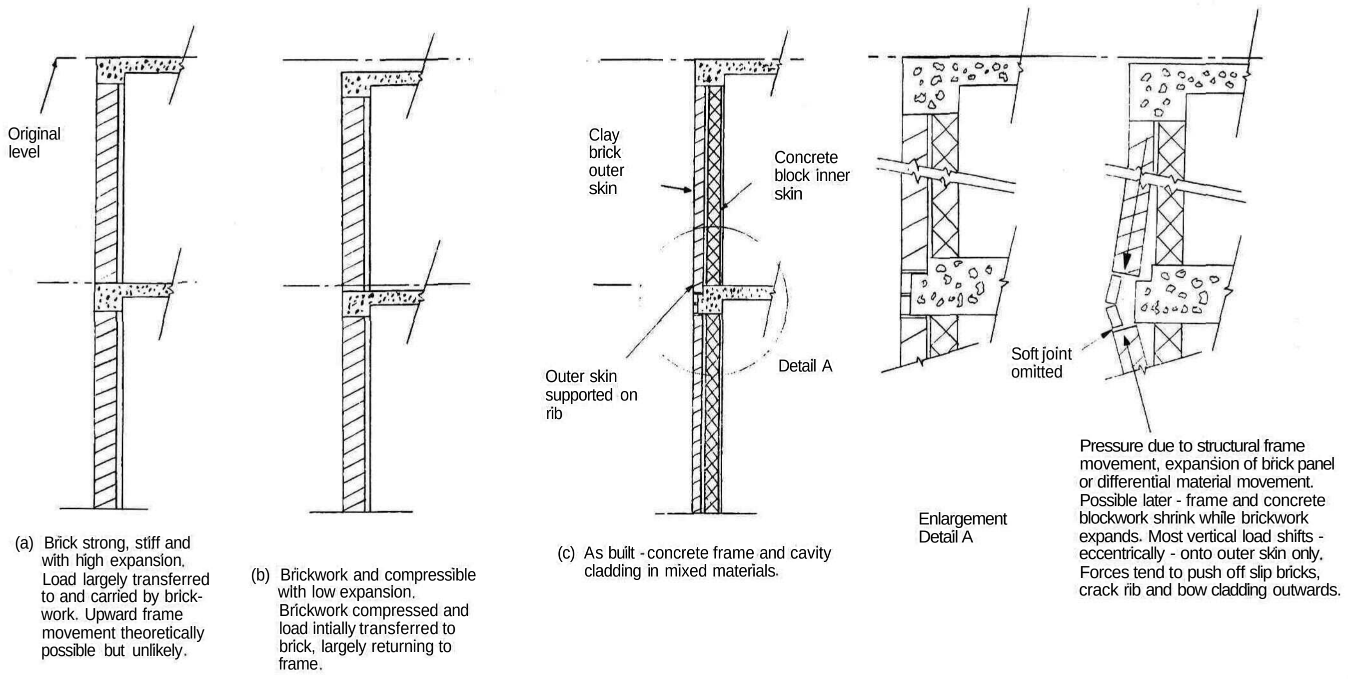
Nature of movement and actual problems

This section needs to be read in conjunction with section 8.4.2. In all structures with masonry cladding there will be small dimensional changes due to:

- combination of initial moisture movements
- creep of concrete under load (where the frame is of concrete)
- elastic shortening of the frame during construction
- cyclic movements due to changes in temperature and, to a lesser extent, humidity including that due to condensation during the life of the building.

Table 8H Movements that may affect cladding

Nature of movement	Type of structure or soil involved	Time of occurrence of movement	Notes
(a) Elastic shortening of columns	All types	Mainly during the construction period, being mostly due to dead load	
(b) Elastic deflection of beams			
(c) Elastic settlement of foundations			
(d) Creep shortening of columns	Reinforced concrete (RC) and prestressed concrete (PSC)	At highest rate immediately after construction and then at reducing rate for, say, 20 years	Best all considered together see 8.4.2
(e) Creep deflection of beams			
(f) Drying shrinkage of cladding	RC, PSC and timber		
(g) Drying shrinkage of cladding	Calcium silicate bricks and concrete blocks only	MOSTLY IN FIRST 5 YEARS	
(h) Moisture expansion of cladding	Clay brickwork only		
(i) Consolidation settlement (or heave)	Clay or silt subsoils		
(j) Racking of frame & loosening of fixings	All types	Any time	Essentially due to wind
(k) Overall temperature changes			Moisture changes also affect timber
(1) Foundation movements (other than (c) or (g) above			See 8.4.3 for discussion of sources of movements



No disruption likely when wall is fully supported - condition also possible for cavity walls

Possible severe disruption when wall is partially supported - more likely with cavity construction.

Fig. 8.2 Effects of forces due to vertical movement

All these movements may be superimposed thus making precise analysis difficult.

Put at its simplest, fired clay products expand gradually after they leave the kiln due to slow take-up of moisture from the atmosphere, while concrete products, being cast wet, shrink as they gradually dry out. Calcium silicate products, including bricks, tend to shrink. BRE Digest 157: 1981 contains useful information. The initial moisture movements are effectively irreversible and are greatest immediately after firing or casting and tail off over a period of some twenty years. There can be dimensional changes in natural stone after quarrying but these are usually relatively small.

The most serious problems have arisen where fired clay in cladding and concrete in frame construction were combined and the movements have been in opposite directions and cumulative. Fig. 8.2 shows diagrammatically the effect of forces due to movement in the vertical plane which tend to be harmful and those which do not. The worst damage has tended to occur in buildings of several storeys with slim and thus weak supporting nibs for the cladding at floor levels. This has also been associated with the use of slip-bricks. In combination, these are two structurally unfortunate architectural fashions of the 1950s to 1970s.

A typical failure with this type of support is shown in Fig 8.2(c). Whereas with robust construction as in Figs 8.2(a) & 8.2(b) there may be transfers of load, damage is unlikely. Much temporary infill in anticipation of an extension to a building has used clay brickwork within concrete frames in heights of up to 9 or 10 storeys and has survived for several decades with no damage discernible either to the frame or to the brickwork.

Similar moisture movements take place horizontally but seldom cause more damage to multi-storey masonry cladding than minor cracks or sliding on damp courses or cavity trays. These are particularly likely in long buildings without joints at parapets and wherever there are short horizontal returns in plan (Figs 8.3 & 8.4). Other points of possible evidence of movement can include corners and around openings.

Another quite common form of damage due largely to moisture movements has been the loosening of thin stone slabs, tiles or mosaic bonded to concrete.

It is important to remember that it is only the moisture movements which take place after the materials are locked into the structure which are significant and that the greater part of these movements will have taken place in, say, the first five years after construction. Thus, when buildings reach the usual time when major cladding maintenance is likely to be considered, all significant moisture movements are likely to have ceased.

Cyclic movements, mainly due to temperature changes, will continue to occur throughout the life of any building and, although these can be serious at roof level, as illustrated by Fig 8.5, short of pronounced ratchet action, they have generally proved less troublesome than those due to initial moisture movements. Cyclic moisture changes can cause significant movement is some materials, such as timber and lightweight concrete block, but may in all construction lead to condensation and deterioration, especially of fixings in cavities.

Precautions against damage due to both moisture and thermal movements have been increasingly introduced into codes of practice and design notes since the 1960s, when movement problems really came to a head. For the most part, these precautions consist of forming soft joints to allow relative movement and the incorporation of often quite complex fixing devices to hold the masonry cladding in place, yet allowing a degree of movement.

Any engineer appraising masonry cladding would do well to find out the date of construction and become familiar with the thinking at that time. A short bibliography is included at the end of this Chapter. It helps to know what to expect and to be able to recognise the time when moisture expansion and concrete shrinkage had been discovered and the time when cracking was wholly blamed on temperature and detailing was planned accordingly.

Treatment of damage due to differential thermal or moisture movements

Where there is cracking or displacement of masonry cladding attributable to long-term thermal or moisture movements, it is tempting to carry out local repairs followed by the provision of new movement joints at 'code' specified centres to prevent a recurrence. The main point is that it is seldom, if ever, desirable to introduce precautions such as cutting movement joints when the movement has largely, if not fully, taken place. With stone cladding, there is a particular danger of causing disruption by such cutting. What is more, precautions introduced, either at the time of building or later to allow for movement may, if not perfect, be a cause of damage.

Local obstructions or bridging of movement joints can cause more trouble than total omission of these. Lack of continuity of cavity tray can cause cracking as shown in Fig 8.5. At such corners the expansion thrust of the outer skin can converge from both directions. Damp proof courses (DPC) allow sliding to take place where it would otherwise be restrained by normal bond. This is also a factor in the parapet movement shown in Fig 8.4.

These are just examples. An appraising engineer needs to look very carefully at the details of any masonry cladding before deciding whether it is adequate or, if not, what form of repair would be best. Above all, the engineer needs to decide whether it is best to restrain movement or to make sure it can take place freely. This decision may be greatly influenced by what precautions against movement have been taken in the past.

Once cladding has been in place for a number of years and the initial moisture movements have virtually finished, there could even be a case for raking out any horizontal movement joints and replacing these with mortar with a view to providing a much greater capacity for vertical spanning and generally increasing the robustness of the construction.

Some will argue strongly against ever solidifiying an existing movement joint. Certainly movement joints should never be packed solid without careful thought but all remedial work requires the balancing of benefits and risks and one should not take a doctrinaire attitude. If, on analysis, the balance of benefits points to restraint being preferable to continuing movement, the joints are best eliminated. Whatever the arguments, it would be prudent to check that seasonal or even diurnal movements can be absorbed before taking such action.

The problem of slip-bricks

The problems with slip-bricks have in the past been associated largely with differential moisture movements, sometimes accentuated by temperature changes, frost and poor workmanship.

Slip-bricks are now acknowledged as an unfortunate innovation. Few, if any, would specify their use today. Nevertheless many are still in place and apparently giving good service. To replace them all because of an unquantifiable risk, which in many cases is negligible, would be an over-reaction.

Appraisal and treatment of slip-bricks

Appraising engineers would do well to:

- inspect all slip-bricks carefully for looseness
- consult maintenance records for any possible problems in the past
- check on the quality and known effectiveness of the bonding materials, if possible
- check on the likelihood of severe frost damage in the area.

Slips partly supported from below - even through mastic joints - are clearly safer than those over openings. Short lengths of slips are obviously less at risk than long ones where the locked up stresses due to potential differential movements must be more severe. Slips over pedestrian areas are clearly more of a danger than those over inaccessible landscaped areas or over low level roofs.

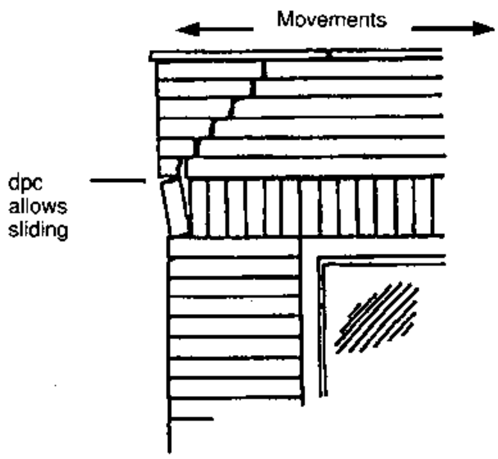
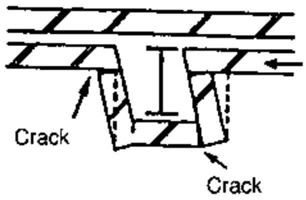
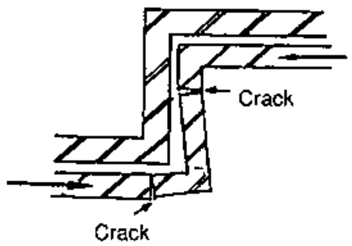


Fig. 8.3 Typical differential movements between brickwork parapet and concrete frame



Typical movement at pier, especially near end of building and in long runs of brickwork



Typical movement at short return

Fig, 8.4 Typical movements at piers and returns

It must be up to individual engineers and surveyors to say whether any surviving slip-bricks should remain. However, there is a strong likelihood that any slip-bricks which have already stood for many years will remain in place for many more, if not indefinitely. Nevertheless some degree of risk must remain and if taken consciously, the owner should be made aware of this and agree to it.

If, for example, only one slip is loose or missing then, assuming that the solution to replace it is accepted, there is a very real problem in deciding what is best to do. Previous experience leads to the recommendation that mechanical fixings should be used for slip bricks or any similar slim cladding units, rather than relying solely on resin or mortar bonding .

Based on current knowledge, one should not rely only upon resin or mortar bonding as a fixing for slip bricks or any other slim cladding units. It is the recommendation of this report that mechanical fixings should generally be used in such cases. However, this may be carring principles too far. There could be situations where resort to bonding could be acceptable, for instance, where there is no danger to people from falling material. In such situations, it must be up to the appraising engineer to seek specialist advice on the best method of bonding. A mechanical fixing should be used in cases of doubt.

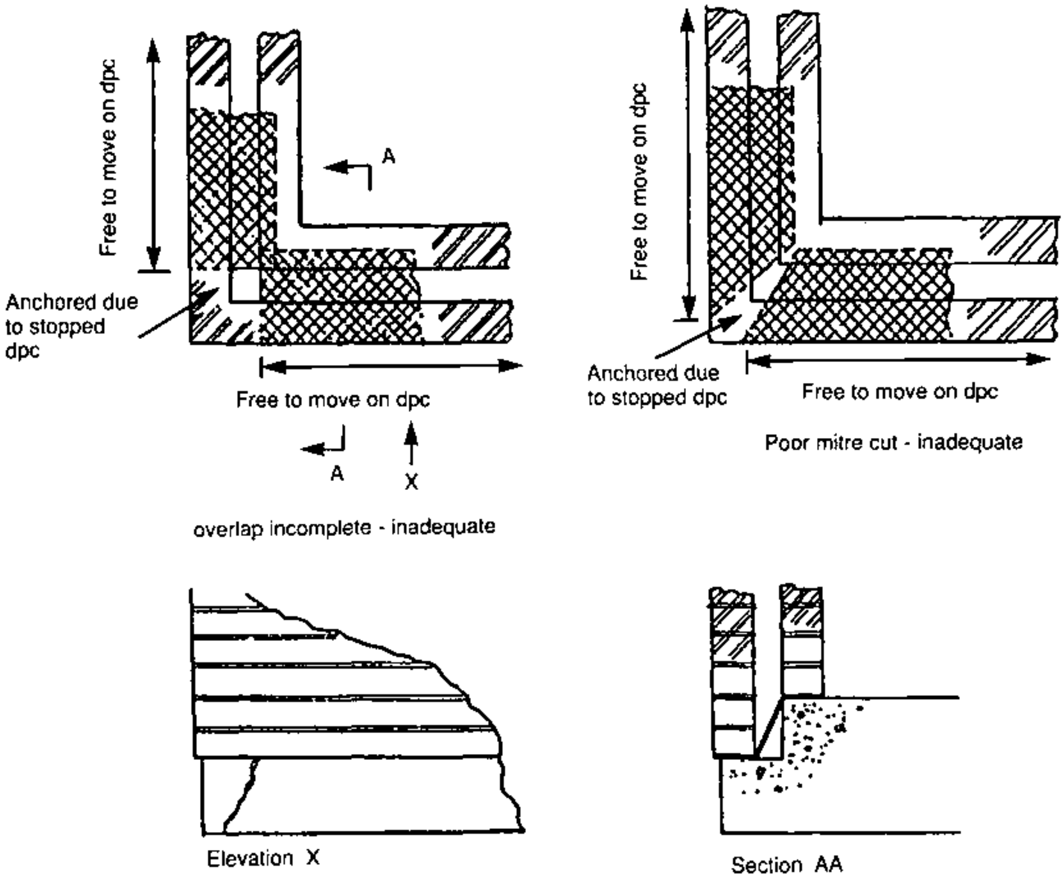


Fig. 8.5 Cracking due to incorrectly stopped dpc with no cornerpiece

8.4.4 Corrosion of steel or iron

The problem

This is a typical defect with early steel framing of the approximate period 1900 - 1950. Earlier examples can be found with wrought iron. Such problems occur particularly when it is clad in decorative terracotta. The symptoms are often slightly irregular cracks in the masonry horizontally or vertically along the lines of the steel framework. One good clue that corrosion may be the cause is when the position and form of cracks cannot be explained by other possible causes such as racking of the whole structure or settlement. If the cracks line up with the positions of beams in the interior, this gives further support to the likelihood of corrosion of stanchions just behind the masonry skin. Glazed brick surfaces to light wells have proved particularly susceptible to this type of corrosion and cracking. Local opening up may be needed to accurately locate and identify the steel (or wrought iron) but if the cover is small, a metal detector or covermeter may give an early indication. Horizontal cracking of masonry may also be due to corrosion of brick ties.

Apart from the unsightliness of this type of cracking there is a real danger of material falling off and causing injury. Further, if the framing is corroding enough to throw off the masonry cladding, there must be a reduction in the strength of the steel member which at least merits investigation.

Most examples of this defect have come to light in structures more than 50 years old. This may be partly just a matter of age but it may also be because steel frames were very common or because protective treatment to the steelwork was not so well advanced as it later became. However it should not be assumed that this danger could not apply to more recent buildings, especially where environmental conditions are particularly aggressive.

Treatment(a)

In general, the best treatment must be to:

- remove the affected cladding
- clear the products of corrosion from the steelwork
- check that the remaining cross-section is adequate
- protect the steel with a modem protective system, and possibly a vertical damp proof membrane
- replace the masonry.

This can be an extremely expensive operation because of the difficulty in most cases of exposing the affected steel and preparing its surface as thoroughly as is normally required in new painting on steelwork.

Treatment (b)

One alternative treatment which has been tried, and has now been proved to be at least superficially successful over a period in excess of fifteen years, is to inject the affected area with resin. This should encapsulate the corroding material and fill any voids in the masonry, thus preventing the entry of water which would cause further corrosion. Care should be taken to use the appropriate injection pressure.

This is particularly appropriate with highly modelled fired-clay materials, e.g. terracotta and faience, or with delicate stonework which would be hard to dismantle without damage and even harder to replace. Columns of these materials quite frequently have iron cores which have no real function once the building is complete and whose corrosion is only detrimental because of the expansive reaction. A weakening of such cores is not in itself dangerous because they do not perform a loadbearing function. However, it must be accepted that the extent and effectiveness of the protection is difficult to check and the long-term efficacy of the repair may be limited. Further, there is a need to monitor such repairs particularly carefully to make sure that there is reasonable security against loosened and falling masonry should the resin penetration not be perfect.

Treatment (c)

Another even simpler method is to rake out all cracks and fill these with mastic so as to minimise, even if not eliminate, all further water penetration. This may be effective with large panels of dense stone like granite but is not likely to be suitable for a material like clay brick or porous stone.

8.4.5 Inadequate spanning capacity of masonry panels

There have been cases where masonry cladding panels to buildings have blown out in very strong winds. These have mostly been gable end panels in buildings with pitched roofs where the masonry has not been adequately tied either to the roof structure or side walls. Large unsupported panels in industrial sheds are also vulnerable. In almost all of these instances, the spans of these walls have far exceeded normal guidelines.

The most difficult problem facing an appraising engineer looking at an example of existing masonry cladding is to decide what to do where the spans exceed those recommended in codes but where there is no sign of damage and where there may well have been several decades of satisfactory service. The most universally accepted criteria for the spanning capacity of masonry panels in Britain are those given in BS 5628 Part 1 : 1978. This code gives two options:

- to adopt a basically geometric approach to spanning capacity using tables derived from full-scale laboratory tests for different proportions of panel and different edge support conditions
- to assess the strength based on arching.

With the first of these methods, it is frequently difficult to justify the spanning capacity where the cladding is spanning in a predominately vertical direction. Here arching is better, providing that there are effective abutments in the form of continuing walls or framing, so that the cladding can arch horizontally, vertically or even diagonally. However, there may be a conflict with allowances for moisture and thermal movements. This is discussed in detail in section 8.4.3.

Obviously, it must be up to the appraising engineer to decide what is adequate but it is always desirable to start from the premise that what is there is satisfactory rather than to condemn hastily because the first check is not encouraging. In most cases, it will not be practicable to improve the spanning capacity of the actual panels by some simple expedient 'just in case...'. Strengthening may not be practicable, or if it is, replacement may prove cheaper. In either case, cost and disruption are likely to be great. Thus, the decision to reject masonry cladding solely on grounds of lateral strength should not be taken lightly. However, a substantial increase in effective spanning capacity is often possible, with little disruption, by improving the edge fixings so as to give a more advantageous set of support conditions, especially in relation to arching.

8.4.6 Inadequate fixings or supporting ledges

The problem of insufficient or inadequately fixed ties

Horizontal ties between the leaves of cavity walls and between complete panels and the structure which support them are frequently less numerous or less well embedded than specified. In many cases the condition and fixity of ties should be sampled and examined in-situ (see test methods in Appendix A and Chapter 6). Similarly, for vertical support the width of bearing, on concrete nibs or shelf angles, may be less than two-thirds of the leaf thickness which is normally taken to be desirable minimum.

The maximum tie spacings for cavity walls stated in BS 5628: Part 1 are intended to provide sufficient connection between the two leaves so that they act together under vertical load so that the assumptions on effective thickness and thus slenderness ratio are valid. These spacings are not necessarily required for cladding where the vertical load is almost negligible. Depending on wind forces, a wider spacing will often be adequate, provided of course that the inner skin or other internal structure provides an adequate anchor.

A first check on the adequacy of the tie spacing in an existing cavity wall can best be made in relation to the relevant wind forces and the characteristic strengths of ties for relevant conditions using Table 8 of BS 5628: Part 1.

Possible action on apparently inadequate ties

If, on the simple basis outlined above, the ties between the leaves of the panels or between the panels and the supporting structure are found to be inadequate or uncertain, a more basic engineering check should be made or a pattern of 'replacement ties' should be drilled in. 'Replacement ties' may in practice be supplementary ties if existing ties are left in position. If serious corrosion of existing ties is taking place, they may need to be removed.

Methods of inserting replacement wall ties are now so numerous and the techniques so well established that it may well be quicker and cheaper to insert a pattern of 'replacement wall ties' rather than struggle to justify wider spacings than those needed to satisfy the 'code' level calculated for wind. The ties, stainless steel bars with either expanding or resin anchorages, are barely visible in most cases and the disturbance in fixing them is small. Further, in some cases, by adding extra ties it may well be possible to secure cladding whose spanning capacity would otherwise be considered inadequate.

Appraising engineers who find problems with the adequacy of ties should consult the CIRIA Report 117 *Replacement ties in cavity walls.* This gives detailed advice on techniques, the assessment of tie requirements and the spacing of extra ties.

The problem of the width of supporting ledges for masonry cladding

Masonry clad framed structures have frequently been found to have inaccuracies of construction beyond the tolerances allowed by the specification, which in some cases can be over-optimistic, combined in some cases with an impracticable specification. This has led to masonry skins being supported on narrower ledges than normally thought desirable, although there may be no sign of distress. It is important to establish whether the apparent inadequacy is local or widespread.

There is a convention that all masonry cladding should be supported over 2/3 of its thickness. On the surface, this looks reasonable but, bad workmanship apart, quite frequently the problems of tolerances and alignment make this width of support difficult to achieve. In some recent cases, expensive and disruptive remedial works have been carried out when the adequacy in the width of ledge has been disputed, but little thought has been given to the real minimum requirement for firm support in the particular circumstances. With remedial treatment, the question which needs to be considered is not just the minimum acceptable width of supporting ledge but, as described below, the level of stability provided by the combination of this width and the horizontal restraint given by the masonry ties immediately above the ledge, see Fig 8.6.

Methods of providing adequate vertical support to masonry cladding

One obvious way of remedying inadequate vertical support to masonry cladding in an existing building is partially to dismantle and provide stainless steel angles firmly bolted to the basic structure on which the cladding sits. Clearly, this is an extremely expensive and disruptive method and, unless well carried out, it

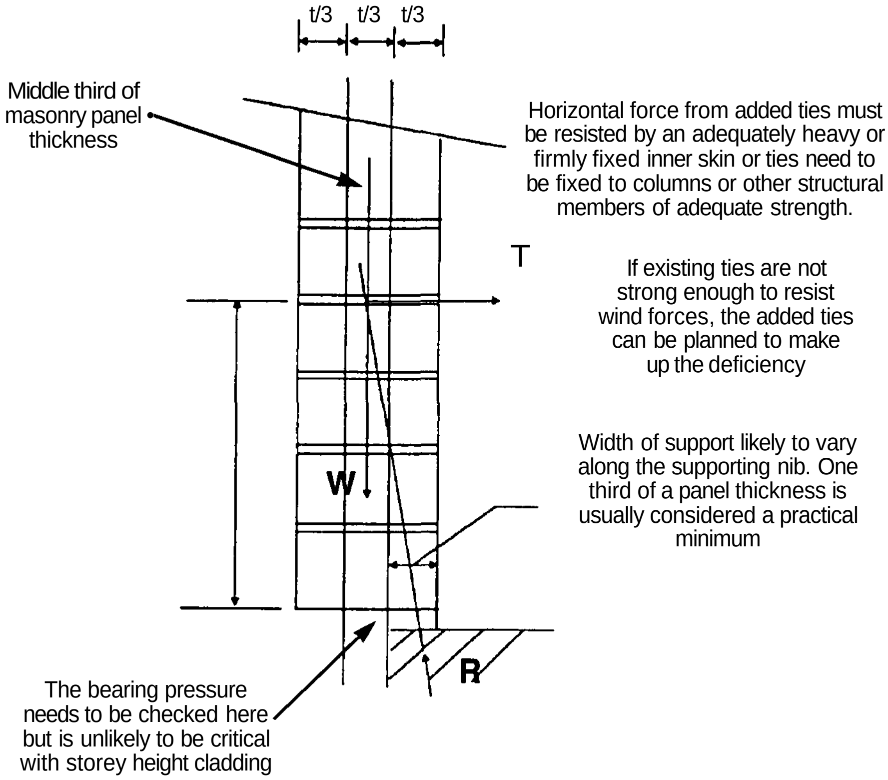


Fig. 8.6 Method ofstabilising a loadbearing masonrypanel with additional ties where the nib isfound to be less than the usual 2/3 ofthepanel thickness

may itself induce a new weakness. However there are other options.

In most cases, this problem of the inadequate width of supporting ledges can also be solved by using extra ties. Most masonry units have a sufficiently high permissible bearing capacity to support a storey high wall on less than of their width. The actual width of bearing needed for the weight of the cladding panel is small and, provided that the panel is tied in firmly at the base, it may well be possible to demonstrate adequate stability in accordance with basic engineering principles by inserting extra ties, if necessary. Where this is possible, it will a host always be cheaper than carrying out remedial work to the nibs or brackets to provide the nominal bearing of 2/3 the thickness of the leaf in question.

The principles of this approach are shown in Fig. 8.6. It can be seen that support widths of 1/3 of the masonry skin thickness or even less can be justified, provided there is adequate tie capacity at the right level. Fig. 8.6 shows the tie compensating for the eccentricity of the outer skin. This approach relies upon assurance of the strength of the ties and the anchorage being in sound and stable material which can provide the necessary horizontal resistance. Many cladding fixings can be taken to columns, edges of slabs or to inner skins clearly capable of spanning between columns, floor slabs, etc.

As previously mentioned, wind and other forces as well as those due to self weight of the cladding must also be allowed for in sizing the ties.

8.4.7 Decay of masonry

The problem

Spalling of the faces of clay bricks and of some natural stones may occur due to repeated cycles of rain and frost. Clay bricks selected to be of a quality in accordance with BS 3921 used in wall cladding above a damp proof course should be resistant to any climatic conditions in the British Isles. It is with calcium silicate bricks, which have been chosen purely for their texture and colour, that the problem is likely to be found. The spalling may only occur on some of the bricks in a wall face, generally the under-burnt ones chosen for their colour.

It is possible but extremely rare for this spalling to be severe enough to have any structural significance. Not surprisingly, the trouble has proved more severe in exposed parts of Scotland and Northern England than in the South.

Treatment of spalled brickfaces.

If the spalling is only local, it may be possible to replace the affected bricks by well burnt ones of the same, or very similar, type. Alternatively, the whole surface may be rendered as is traditional in much of Scotland (see section 8.2). If the spalling is severe and rendering is not acceptable visually, there is probably no alternative to complete replacement with more suitable bricks. However, this brings in the possibility of future damage due to the moisture expansion of large areas of new clay brick.

Clear sealing liquid applications are not generally advisable because of their limited life and because unless applied evenly especially at the edges, they tend to let in water, trap it locally and make the danger of spalling even greater. Clear stabilising solutions or coloured surface treatments which allow the masonry to breathe are sometimes advocated but these should only be used when they have been shown to be suitable for the particular form of masonry and situation.

General advice on mortars for the repair of masonry cladding

Apart from the refixing of slip-bricks or thin & ins of stone, traditional mortars of cement, lime and sand are preferable to resins or other high bond mortars for repair to masonry cladding. The reason is that the longevity of traditional mortars using well graded sand is more certain, as is their fire-resistance. What is more, repairs with cementitious bonding are usually easier to adjust or add to than those with polymer bonding.

8.5 modern structural framing and panel cladding systems

8-51 Structural concern

It is accepted that the repair and maintenance of cladding may be undertaken for reasons other than concern for structural safety. However, for whatever reason work is to be carried out, detailed information should be obtained regarding the reliability

Element/layer	Interface		Material	Condition	Fastening type	Condition
1	External face	*Anodised aluminium*	*Internal corrosion*			
	A	Fastening ext. face			*Alloy rivets*	*Good*
2		Panel frame	*Aluminium structural alloy*	*Local corrosion*		
	B	Fastening panel Frame or external face/sub-frame			*Alloy hook bolts*	*Electrolytic corosion*
3		Sub-frame Horizontal Vertical Both horizontal and vertical	*Mild steel horizontal tee sections*	*Local electrolytic corrosion*		
	C	Fastening Sub-frame/main structural frame			*Mild steel bolts*	*Good*
					Mild steel brackets	*Upperfaces corroded*
					Exp. bolts	*Some loose*
4		Main structural frame	*RC frame*	*Good*		

Fig. 8.7 Proforma for investigations - italics indicate items to be completed by the investigator

of the existing cladding fixings and any evidence should be obtained to predict possible deterioration in the future. Occasionally, however, investigation is carried out purely out of structural concern, for example as a result of:

- suspected inadequate original fastenings
- changes in the use or behaviour of the structure
- changes in the exposure to external forces, e.g. wind or seismic risks
- impact or other physical damage
- suspected deterioration in the structural properties of the materials likely to reduce the load capacity of fixings or weaken the zones of cladding materials to which they are attached.

8.5.2 Checklist of headings for investigation

The cladding envelope generally consists of several layers interconnected by fixings which to some degree perform a 'structural function'. Each investigation might therefore merit the preparation of a chart for recording conditions at key cladding positions. The nature and integrity of materials and their fixings and fastenings can be recorded layer by layer and interface by interface. Fixings and four possible cladding component layers are referred to below. For the purpose of the general review, the materials of the four possible layers of the construction are suggested in the following sections.

Fixings and fastenings

All connections, including fixings and anchors - collectively referred to as fastenings, are subject to forces due to gravity, wind loading, differential movements caused by thermal and moisture changes and other effects such as those described above. Forces are variable and sometimes cyclic. In some circumstances, they can be unpredictably accumulative. The latter cases arise when there has been inadequate provision for thermally induced movement where expansions are not followed by free contractions. Forces can be generated by this ratchet effect which are referred to as 'slip stick' behaviour.

The variety of forms and materials which comprise the wide range of fastenings, including fittings and bracketing likely to be used, are described in Chapters 6 and 7 .

Since the holding together of cladding components and their secure fixing to the structure is the prime structural concern, it is the effectiveness of the fastenings in each layer which form the primary focus of the investigation. The investigation should also check the condition of the material adjacent to the fastening upon which it also relies for its effectiveness.

Existing panels may be of homogeneous materials fixed directly to the structural frame or they may, as with curtain walling, require a subframe or, as spandrel panels, a carrier frame.

External surface materials of cladding panels

These may be of:

- glazing (single or multi-layer)
- metal sheeting (mill-finished, anodised or coated aluminium, galvanized or coated steel, stainless steel), plain or ribbed
- fibre reinforced polyester or cementitious material
- precast concrete, composite with some other surface material or with special surface finishes such as exposed aggregate.
- laminated products, generally of plastic materials.

Panel-framing materials

Commonly used materials include:

- metals, e.g. steel or stainless steel (hot or cold rolled cold formed), aluminium alloy, (formed or extruded), metals protected by coatings, galvanised or anodised
- precast concrete framing, usually provided integrally with the concrete panel, but may enclose or protect other materials, particularly insulation layers
- structural quality timber
- plastic and composite sections.

Panel forming materials

The backing to an external surface may be of any of the materials referred to above, often incorporating a form of insulation. This insulation may be preformed and attached to the external or inner lining surfaces or it may be site assembled as sandwich insulation.

Sub-frame materials

These are usually in the following forms:

- sub-frames for metal, glass and panel materials other than concrete are generally of metal or the same material as the panel
- precast concrete sub-frame to large precast cladding panels are generally attached directly to the main frames. Where lighter precast products are a component of curtain walling, they may be mounted on metal sub-frames
- structural timber
- plastic and composite sections.

8.5.3 Repair characteristics of material to be assessed

Glazing and metal sheeting which is unsatisfactory will almost certainly need to be replaced. Panels of some materials may be refaced, whether the framing be metal or timber.

Facing panels of plywood or composites are themselves generally faced with a decorative or protective material which is dificult to reinstate and the whole panel may need to be replaced. Precast concrete panels, which generally provide a complete external envelope, are often capable of effective local superficial repair but it is important to detect circumstances where more fundamental problems exist. Only after thorough investigation can the extent of viable repair be assessed and the future longevity and safety of a repair be estimated. The principles of investigation and repair of exposed concrete surfaces are well described in the CIRIA publication, *Book 1 Corrosion damaged concrete.*

Precast panels have frequently been faced in manufacture with stone or reconstituted stone. Concrete surfaces have also sometimes been subject to surface treatments to expose aggregate. Such treatment may have affected the durability of the panels. Where facing mixes are different from the main panel concrete they are likely to be more permeable, may not have bonded perfectly and the reinforcement may inadvertently be close to the interface. These characteristics would have rendered the surface layers more vulnerable to reinforcement corrosion. Such corrosion would create a danger of spalling or delamination of the facing mix, possibly loosening concrete in plate-like lumps.

Brick and block masonry built at site is dealt with in section 8.4. The same materials have been used as a facing material to precast concrete panels. Prefabricated reinforced masonry has also, though rarely, been used in independent panel form. The advice in section 8.4 may therefore be relevant if these are subject to investigation.

8.5.4 Panel repair

Repairing or renovating the existing cladding for cosmetic, water penetration or structural reasons will almost certainly require access externally for the work to be done and for new materials to be hoisted. Design and specification of the repair should take into account lifting apparatus appropriate to the task. Forms of access and lifting arrangements should be chosen from the point of view of the safety of workers, the safety of the public and the safety and convenience of any occupants of the building. It should be remembered that where sound workmanship is required, the best possible working conditions must be provided. Inspection and supervision areas important for repairs as for new work and this requires good access and good co-operation between those specifying, carrying out the work, and those checking it.

A repair programme may only involve the replacement of individual panels and the removal and replacement of seals and fixings. The repair specifier should take full account of the causes of defects as deduced from a previous investigation and make an assessment of the expected service life of the new materials. These should be chosen to be compatible with the life of the cladding being repaired or with any expected resealing cycle.

As mentioned in section 8.5.3, existing concrete panels may require repairs to exposed aggregate surfaces, ribbed or plain surfaces possibly cracked or spalled due to corrosion, cracks or comer damage. These may be partly attributable to local defects in manufacture or handling or due to unintended restraint against movement. Advice on dealing with all these problems can be found in the general literature of concrete repair. In particular, a paper by Dr Plum, published in *The Structural Engineer,* quoted in the bibliography should be noted. This is particularly helpful in deciding what repair material to specify. Tests for repair materials have not yet been standardised but European standards are in preparation. Meanwhile, CIRIA Technical Reports 139,140 and 141 provide guidance to the tests currently used.

For future safety, the cause of deterioration should be determined. Although work may sometimes be superficially referred to as 'repairs,' it should always be specified and supervised by a specialist with expertise in the materials involved and their structural properties. A structural engineer should always assess the forces and capacity of new and existing fixings of all cladding elements including insulation. They should be provided with adequate restraint back to the basic structural frame, but fixings and support should allow for the appropriate degree of differential movement between cladding and frame.

8.5.5 Recladding

Recladding is likely to involve an entirely new system either of curtain walling, masonry or precast concrete. Each of these can provide cladding which supports no load apart from its own weight and the environment forces which act upon it. Such a provision, forming a continuous sealed separation of the internal and external environments, positioned outside the structural frame and not consisting solely of large precast concrete panels or masonry, is loosely described as 'curtain walling'. A characteristic of curtain walling is that it requires vertical and horizontal sub-frame structural elements designed to support panels of various materials, generally conforming to a standard module.

Precast concrete recladding will generally be fixed directly to the edge beam or floors of the frame. Relatively few, but very substantial, fixings are therefore required for precast concrete recladding. The design of the fixings should make ample allowance for the irregularities of the frame, deflections of the slab edges and manufacturing tolerances of the panels. Large panels should be fixed against all movement at one support only, allowing for seasonal and diurnal differential movement in two dimensions between the panel and the frame in all other bearings and restraints.

8.6 Overcladding

Overcladding is often undertaken as a form of renovation. Buildings are often overclad to give protection against a failed cladding system, to improve insulation or simply to provide aesthetic variation. A common example of this is where concrete cladding has deteriorated and spalling has reached an unacceptable level. The technique can usually be executed without the need to evacuate building occupants. Rainscreen cladding has been briefly referred to in section 7.9 but its technology can be used in overcladding. Alternatively, it can be face-sealed.

It is essential for the engineer to gain an accurate and detailed knowledge of the cause of the original problem and also to be certain of those locations where new structural support may be obtained with safety. Before new support fixings can be detailed, it is essential to carry out an accurate dimensional survey of the relevant elevations.

Any new cladding system should permit ventilation of any cavity to minimise possible condensation and future degradation of the structure. Thought should also be given to restricting potential fire paths through the cavity (see also section 8.1.5) and also to provide a trap to collect any falling debris which may continue to become detached. General advice on design and detailing is given in Chapter 7.

Most overcladding systems will consist of lightweight metal panels, usually aluminium but possibly stainless steel. Good practice would include, inter alia, attention to the following:

- use of initially flat panels to avoid 'canning' or buckling
- robustness and stiffness
- avoidance of vibration and fatigue
- continuity of cladding up and over parapets
- structural and drainage continuity in vertical channel supports
- avoidance of 'chattering' and lateral creep of panels by carefully detailed support arrangements
- equalisation of panel edge stiffness so panels flex in harmony

- welding to panel comers to resist concentrations of load
- closing cavities at comers of buildings to better resist wind turbulence and the local effects of positive and negative pressures
- use of membrane theory in panel design. (see Constrado Monograph *Thin Plate Design for transverse loading* by B. Aalami & D. G. Williams).

The practice of overcladding existing brickwork with stone or simulated stone facings bonded to the brickwork is not recommended. If such a practice is contemplated, then any adhesive bonding should be enhanced with mechanical fixings. Overcladding, where feasible, is a solution which is attractive in that the external appearance of the building can be entirely changed, its insulation can be enhanced and its structure can be protected against deterioration due to exposure as well as providing an additional safeguard against elements of the previous cladding falling off. The expense of removing the existing cladding and evacuating the building is also avoided.

However, a BRE publication (H. W. Harrison, J. H. Hunt, J. Thomson: *Overcladding exterior walls of large panel system dwellings:* BRE, 1986) places these advantages in perspective in relation to large panel systems. It warns that not all large panel systems are suitable for this treatment and that the additional public safety which such a solution may provide still depends on the security of the original panels, the fixings of which may continue to deteriorate.

Fixing overcladding directly to existing cladding must be carefully considered and the existing fixings fully investigated. It advises that the environment created within the original cladding material and enclosed space and at the interface with the new cladding is uncertain. It also accepts that it is therefore difficult to predict whether the life of the existing cladding will be enhanced or whether there is a risk to accelerating the deterioration of cladding or fixings.

8.7 Fixings for repair and renovation

The general approach to design of fixings is given in Chapter 7 Recladding, overcladding and rainscreen cladding may change the wind permeability of the cladding envelooe to an extent which might affect maximum loads on fixing due to wind. Wind pressures derived as advised in Chapter 5 may not allow for the variations in forces which occur in the ties, bolts, brackets and anchors (fastenings) within the thickness of the cladding. Fluctuation in the internal pressures out of phase with those applied to the external surfaces provide dynamic cyclic effects which fastenings should withstand.

8.8 Fire damage reinstatement

Following fire damage investigation and assessment (see section 8.1.5) remedial work to fire damaged cladding, where practicable, can usually follow the procedures advised for other forms of damage. Heat and flame contact with the surface of masonry for a short time may mean that repointing may be advisable, spalled stones or bricks may need replacement, refacing and rendering may need to be overhauled if not replaced.

After masonry has suffered a more prolonged heating of greater intensity, it may be necessary to investigate the residual strength of mortar and masonry units where walling stength or fixings into masonry have any structural significance. Such investigation may be by means of in-situ tests or on representative couplets carefully removed and tested in the laboratory.

Local fire damage to concrete panels can usually be treated in the same way as any other fire damage to reinforced concrete but, depending on the results of inspection and tests, the fixings may be supplemented if not entirely replaced.

In view of the wide variety of cladding materials, fixings and systems and their respective vulnerabilities, it is not appropriate to attempt to give specific or further general advice on remedial work.

8.9 References and bibliography

Note: See Appendix B for a listing of full titles of British and European Standards referenced in the text. Some other relevant standards are also listed-

Institution of Structural Engineers. *Appraisal of existing structures.* London: IStructE, 1980. (under revision)

Alexander, S.J. and Lawson, R.M.: *Design for movement in buildings.* London: CIRIA, 1981. (CIRIA Technical Note 107)

Concrete Society report no. 15

Oil Mastics English Heritage Practical Building Conservation

Ashurst, John and Ashurst, Nicola: *Practical building conservation: Volume 3: mortars. plasters and renders.* Aldershot: Gower Technical-Press, 1988. (English Heritage Technical Handbook).

External rendered finishes. Watford: Building Research Establishment, 1976. (BRE Digest 196).

Addelson, Lyall: *Building failures: a guide to diagnosis, remedy and prevention.* 2nd ed. London: Butterworth Architecture, 1989.

Lead Development Association. *The lead sheet manual: a guide to good building practice. London:* Lead Development Association, 1990 -.

Lead Development Association. Leadwork quarterly joumal,

Institution of structural Engineers. *Subsidence of low rise buildings.* London: SETO Ltd, 1994.

Calcium silicate (sandlime. flintlime) brickwork. Watford: Building Research Establishment, 1992. (BRE Digest 157)

Tutt, J N.: *Replacement ties in cavity walls: a guide to tie spacing and selection.* London: CIRIA, 1988. (Report 117.)

Pullar-Strecker, Peter: *Corrosion damaged concrete: assessment and repair.* London: CIRIA; Butterworths, 1987.

Plum, D. R.: *Standard tests for repair materials and coatings of concrete*

McLeish, A.: *Standard tests for repair materials and coatings for concrete: part1 :pull-off tests.* London: CIRIA, 1993. (Technical Note 139.)

Leeming, M.B.: *Standard tests for repair materials and coatings for concrete: part2: permeability tests.* London: CIRIA, 1993, (Technical Note 140,)

Kay, E.A. et al.: *Standard tests for repair materials and coatings for concrete: part 3: stability, substrate compatibility and shrinkage tests.* London: CIRIA, 1993. (Technical Note 141.)

Aalami, B. and Williams, D.G.: *Thin plate design for transverse loading.* London: Crosby Lockwood Staples, 1975.

Harrison, H.W., Hunt, J.H. and Thomson, J.: *Overcladding exterior walls of large panel system dwellings.* BRE, 1986.

Anderson, J. M. and Gill, J. R.: *Rainscreen cladding: a guide to design principles and practice.* London: CIRIA; Butterworth, 1988.

Holland, R Montgomery-Smith, B.E. and Moore, J.F.A.: *Appraisal and repair of building structures: introductory guide.* London: Thomas Telford, 1993.

Wilson, M. and Harrison, P.: *Appraisal and repair of claddings and fixings.* London: Telford, 1993.

Institution of Structural Engineers. *Guidance note on the security of the outer leaf of large concrete panels of sandwich construction.* London: IStructE, 1989.

Currie, R. J. and Robery, P. C.: *Repair and maintenance of reinforced concrete.* Watford: BRE, 1994, (BR 254.)

Lawson, M.: *Steel overcladding of existing buildings.* London: BCSA and Ascot: SCI. 1994. New Steel Construction.

Ryan, P.A. et al: *Durability of cladding.* London: Thomas Telford Ltd. 1994.

9 Research

9.1 General

Many different materials and forms of construction relating to cladding and curtain wall for buildings have been referred to in the compilation of this report. These include various metals, natural materials like stone, synthetic materials like plastics or glass reinforced concrete as well as composite faced decorative panels and insulated composite panels.

Forms of construction vary from materials fixed directly to the walls or structure of the building to overcladding and fully framed curtain wall and cladding where the framework retains individual panels and is fixed to the building structure. In addition to this the environment and its effect on the building have been considered. The major influences of wind loading, temperature and corrosion are all important as are the construction related area of tolerance and fabrication methodology.

Many of the materials and technologies mentioned above are the subject of research and development, usually in very specific ares. This Chapter identifies and lists the areas needing further study. Areas where work is known to be ongoing or recently completed are indicated.

9.2 Areas for Research and Development

9.2.1 General

These include:

- Quantification of building stiffness and building movements in service including wind load effects and thermal movements. BRE research ongoing at their Cardington facility on a full size building frame. They hope to investigate the stiffening effect of the cladding.
- Fire performance. Current BRE work at Cardington involves full scale fire testing of performance of cladding systems.
- Effects of blast loading on cladding and curtain walls, safety and design to mitigate the effects of blast.

9.2.2 Materials

Concrete

Behaviour of resin and mechanical anchors in cracked concrete requires research.

Glass

Research required in this area includes:

- Spontaneous fracture of toughened glass.
- Structural design of glass, design parameters, methods, standards, etc.
- Design of mechanical supports to glass panels.
- Design criteria, methods and standards for structural glazing using sealants.
- Performance of glass in fires.
- Impact resistance of glass in frames.

The Centre for Window and Cladding Technology (CWCT) based in Bath University have done some testing and may well initiate future research in some of the above areas of glass technology.

Metals

Research required in this area includes:

- Corrosion, durability and repair of coated metal claddings.
- Composite action of aluminium curtain wall grid members across a plastic thermal break.
- Stresses in aluminium curtain wall components due to service loadings and their treatment in BS 8118

Masonry

Research required in this area includes:

- Shear and creep in masonry.
- Thin stone facings and reinforced stone panels - performance durability and variability of the materials.

Fibre reinforced materials

Research is needed on fibre reinforced plastic materials, their properties, durability, avoidance of failure using this material.

Appendix A Tests suitable for cladding elements and their fixings

A1 Instruments and materials

A1.1 Cover meter
A simple electromagnetic technique for measuring the depth, orientation and distribution of steel reinforcement in concrete. (BS 1881: Part 204: 1988)

A1.2 Radiographic techniques
Gamma and X-rays may be used to examine the interior of relatively thick concrete members for the presence of voids, poor compaction, continuity of grouting in prestressing ducts and layout of reinforcement. (BS 1881: Part 205: 1986, BS 3683: Part 3: 1984)

The technique may also be used to determine quality and integrity of structural steel. (BS 2600: Part 1: 1983/Part 2: 1973)

A1.3 Electrical techniques
Measurement of electric potential between parts of concrete members can be used to give an indication of corrosion of reinforcement. (Gernety, M. W.: Highway Research Board Bulletin No. 182 California, 1957)

A1.4 Endoprobe
These are optical devices that may be used to inspect the presence and integrity of cavity wall ties, and are also of use in inspecting prestressing ducts.

A1.5 Ultrasonics
The quality of concrete can be assessed by measuring the velocity of ultrasonic pulses through it. (BS 1881: Part 203: 1986 BS 3683: Part 4: 1985). For steel and other metals, ultrasonics, while providing similar information to radiographic techniques will, in addition, indicate laminations in the parent material. (BS 3683: Part 4: 1985 BS 2704: 1983 BS 3889: Part 1: 1983)

A1.6 Rebound hammer
This is a simple technique for assessing quality of concrete by testing its surface hardness. (BS 1881: Part 202: 1986)

A1.7 Coring
Standard cores (100 or 50mm Φ)may be cut from suspect concrete for measurement of actual strength or density. For situations where standard cores cannot be obtained, smaller cores can be taken. (BS 1881: Part 120: 1983)

A1.8 Internal fracture test for concrete
This test, sometimes called the 'pull-out test,' measures the strength of concrete by pulling on an anchor in the concrete until internal fracture occurs. This test may be modified to check efficacy of bolt fixings etc. (Chabowski, A. J. & Bryden Smith, D. BRE CP25/77)

A1.9 Detection of cracks using ultraviolet (uv) lights
Very fine cracks in concrete may be detected using UV light if the surface is treated with fluorescent flow detector.

A1.10 Absorption
Absorption tests can be made on small (75mmm) cores from concrete. Initial tests may be carried out to measure surface absorption of concrete without damage to the structure. (BS 1881:Part5: 1970/Part122: 1983)

A1.11 Cement type/content, aggregate type & aggregate /cement ratio, water/cement ratio
These may require a complete chemical analysis by an analytical laboratory. If the type of aggregate is not readily identifiable by inspection, then thin section petrographic analysis may be required. (BS 1881: part 124: 1988)

A1.12 Admixtures and contaminants
Many admixtures are used in concrete but the most damaging may be calcium chloride. (BS 1881: Part 124: 1988)

A1.13 Free lime – depth of carbonation
Alkali environment in concrete acts as a rust inhibitor to embedded steel. If corrosion is suspected it may be necessary to determine depth of carbonation. (Parrott, L. J.: *A review of carbonation in reinforced concrete.* BRE, 1987.)

A1.14 Optical tests
To verify dimensions of members, visual measurements obtainable with rules, tapes, callipers and micrometers will usually suffice. More sophisticated optical methods are available using lasers, X- and Gamma rays.

A1.15 Recognition of cast/wrought iron
Cast iron may sometimes be identified by surface evidence of the casting process. Wrought iron may be readily identified by its characteristic laminated structure. If a small patch is ground in the surface to expose clean metal and then polished with abrasive, slag filaments,visible through a hand magnifying glass will identify the material. (Sutherland, R. J. M.: *Construction Materials Reference Book:* Butterworth-Heinemann 1992 Chapters 3 & 4)

A1.16 Mechanical properties of timber
Usually established by visual or machine stress grading. (Sunley, J. G.: *Construction Materials Reference Book* Butterworth-Heinemann 1992 Chapter 50)

A1.17 Moisture content of timber
Moisture content of solid untreated timber can usually be determined by portable battery-operated moisture meter.

A1.18 Identification of chemical preservatives
Green tinges to timber usually indicates use of copper/chrome arsenic salts. Most specialist firms using a small kit will be able to identify their particular brand of preservative.

A1.19 Identification of insect attack or rot in timber
'There are two main pests that infect constructional timber, i.e.:

- the common furniture beetle
- the house longhorn beetle.

Specialist guidance is usually necessary to ensure correct identification.

Early signs of fungal attack leading to wet or dry rot are not easy to identify without specialist laboratory equipment.

(Bravery, A. F. et al: *Recognising wood rot and insect damage in buildings:* BRE: 1992)

A1.20 Tests for durability of stone

Tests for durability of limestones, sandstones and slates can be carried out. (Ross, K. D. & Butlin, R. N.: *Durability tests for building stone.* BRE. 1989)

A1.21 Additional tests

There are additional, more specialised tests available to the engineer. For further guidance, particularly when appraising existing cladding, reference should be made to the Institution of Structural Engineers report *Appraisal of existing structures,* currently under revision.

Attention is also directed to BS 1881 : Part 201 : 1986 *Guide to the use of non-destructive methods of test for hardened concrete.*

A2 Testing of cladding assemblies

A2.1 Basic tests

The basic tests listed below can be performed:

- Air permeability. (BS 5368: Part 1: 19??)
- Watertightness. (BS 5368: Part 2: 19??)
- Wind resistance. (BS 5368: Part 3: 19??)

A2.2 Additional tests

Further tests can also be carried out if required:

- Thermal cycling to assess likelihood of condensation.
- Impact testing. (BS 8200, BS 6206)
- Structural testing of individual components, e.g. mullions.
- Racking tests to simulate structural movement of seismic loading.

Appendix B Relevant British and European Standards

BS 187: *Specificationfor calcium silicate (sandlime & flintlime) bricks.* 1978

BS 402: *Clay roofing tiles &fittings,* Part 1: *Specification for plain tiles & fittings.* 1990

BS 473,550: *Specificationfor concrete roofing tiles and fittings.* 1990

BS 476: *Fire tests on building materials and structures.* Parts 3,4,6,7,10,11,12,13,20,21,22&23. 1975-91

BS 481: *Specification for industrial wire mesh,* Part *2: High tensile steel wire mesh with square apertures from 125mm to 2mm.* 1983

BS *544: Specification for linseed oil putty for use in wooden frames.* 1969

BS 690: *Asbestos-cement slates & sheets,*

Part 2: *Specification for asbestos cement & cellulose-asbestos cementflat sheets.* 198 1.

Part 3: *Corrugated sheets.* 1989.

Part 4: *Slates.* 1974.

Part 5: *Lining sheets &panels.* 1975.

Part 6: *Fittingsfor use with corrugated sheets.* 1976.

BS 729: *Specification for hot dip galvanised coatings on iron and steel articles.* 1986

BS 849: *Code ofpracticefor plain sheet zinc roofing.* 1939

BS 915: *Specific1ationfor high alumina cement.* Part 2: *Metric units.* 1983

BS 952: *Glassfor glazing,* Part 1: *Classification.* 1978

BS 970: *Specification for wrought steels for mechanical and allied engineering purposes.* Part 1 : *General inspection and testing procedures and specific requirements for carbon manganese, alloy and stainless steels* (T). 199 1

BS 1140: *Specification for resistance spot welding of uncoated and coated low carbon steel.* 1980

BS 1161 : *Specification for aluminium alloy sectionfor structural purposes.* 1991

BS 1202: *Specificationfor nails,* Part 3: *Aluminium nails.* 1974

BS 1203: *Specification for synthetic resin adhesive (phenolic and aminoplastic) for plywood.* 199 1

BS 1204: *Specification for type MR phenolic and aminoplastic synthetic resin adhesivesfor wood.* 1993

BS 1217: *Specificationfor caststone.* 1986

BS 1369: *Steel lathing for internal plastering & external rendering,* Part 1: *Specification for expanded metal & ribbed lathing.* 1987

BS 1400: *Specificationfor copper alloy ingots and copper alloy and high conductivity copper castings.* 1985

BS 1449: *Steel plate, sheet and strip.* Part 2: *Specification for stainless and heat-resisting steel plate, sheet and strip.* 1983

BS 1470: *Specification for wrought aluminium and aluminium alloys for general engineering purposes: plate, sheet and strip.* 1987

BS 1473: *Specification for wrought aluminium and aluminium alloys for general engineering purposes* - *rivet, bolt and screw stock,* 1972

BS 1474: *Specification for wrought aluminium and aluminium alloys for general engineering purposes: bars, extruded round tubes and sections.* 1987

BS 1475: *Specfcation for wrought aluminium and aluminium alloys for general engineering purposes - wire.* 1972

BS 1490: *Specification for aluminium and aluminium alloy ingots and castings for general engineering purposes.* 1988

BS 1521 : *Specification for waterproof building papers.* 1980

BS 1615: *Method for specifying anodic oxidation coatings on aluminium and its alloys.* 1987

BS 1706: *Method for specifying electroplated coatings of zinc and cadmium on iron and steel.* 1990

BS 1724: *Specificationfor bronze welding by gas.* 1990

BS 1795: *Specification for extendersfor paints.* 1991

BS 1832: *Specification for compressed asbestos fibre jointing.* 1991

BS1881:*Testingconcrete.*Parts5,120,122,124,201,202,203,204& 205. 1970-88

BS 1974: *Specification for large aluminium alloy rivets (1/2 in to 1 in nominal diameters)* (Obsolescent). 1953

BS 206 1 : *Specfcation for phosphor bronze spring washers for general engineering purposes.* (Obsolescent). 1953

BS 2569: *Specification for sprayed metal coatings,* Part 1: *Protection of iron and steel by aluminium and zinc against atmospheric corrosion.* 1988

BS 2600 *Radiographic examinationoffusion welded butt joints in steel.*

Part 1 : *Methods for steel 2mm up to and including 50mm thick.* 1983.

Part 2: *Methods for steel over 50mm up to and including 200 mm thick.* 1973.

BS 2704: *Specification for calibration blocks for use in ultrasonic flow detection.* 1983

BS 2752: *Specification for chloroprene rubber compounds.* 1990

BS 2870: *Specification for rolled copper and copper alloys: sheet, stip and foil.* 1980

BS 2874: *Specification for copper and copper alloy rods and sections (other than forging stock).* 1986

BS 2901 : *Filler rods and wires for gas-shielded arc welding,* Part *4: Specification for aluminium and aluminium alloys and magnesium alloys.* 1990

BS 2996: *Specification for the projection welding of low carbon wrought steel studs, bosses, bolts, nuts and annular rings.* 1958

BS 3019: *TIG welding,* Part 1: *Specification for TIG welding of aluminium magnesium and their alloys.* 1984

BS 3083: *Specification for hot-dip zinc coated and hot-dip aluminium/zinc coated corrugated steel sheets for general purposes.* 1988

BS 3379 : *Specification for flexible polyurethane cellular materials for loadbearing applications.* 1991

BS 3451: *Methods of testing fusion welds in aluminium and aluminium alloys.* 1981

BS 3683: *Glossory of terms used in non-destructive testing,*

Part 3 *Radiologicalflaw detection.* 1984.

Part 4 *Ultrasonicflaw detection.* 1985

BS 3712: *Building and construction sealants.*

Part 1 : *Methods oftestfor homogeneity. relative density & penetration.* 1991.

Part 2: *Methods of test for seepage, staining, shrinkage, shelf-life and paintability,* 1986.

Part 3: *Methods of test for application life, skinning properties & tack-free time.* 1986.

Part *4: Method oftestfor adhesion in peel.* 1991

BS 3889: *Methodsfor non-destructive testing of pipes and tubes* Parts 1,2A&2B. 1987-91

BS 3921 : *Specificationfor clay bricks.* 1985

BS 4016: *Specificationfor buildingpapers (breather type).* 1972

BS 4021: *Specification forflexible polyurethane foam sheeting for use in laminates.* 1984

BS 4254: *Specificationfor two-part polysulphide based sealants.* 1991

BS 4255: *Rubber used in preformed gaskets for weather exclusionfrom buildings,* Part 1: *Specificationfor non-cellular gaskets.* 1992.

BS 4466: *Specification for scheduling, dimensioning, bending and cutting ofsteel reinforcementfor concrete.* 1989

BS 4486: *Specificationfor hot rolled andprocessed high tensile alloy steel barsfor the prestressing ofconcrete.* 1980

BS 4551 : *Methods of testing mortars, screeds & plasters.* 1980

BS 4576: *Unplasticised polyvinyl chloride (PVC-U) rainwater goods and accessories,* Part 1 : *Half-round gutters & pipes of circular cross-section.* 1989

BS 4624: *Methods oftestfor asbestos-cement building products.* 1992

BS 4652: *Specification for metallic zinc-rich priming paint (organic media).* 1979

BS 4721: *Specificationfor ready-mixed building mortars.* 1986

BS 4841 : *Rigidpolyurethane (PUR) and polyisocyanurate (PIR) foam for building applications,*

Part 1 : *Laminated boardfor general purposes.* 1975.

Part 2: *Laminated board for use as a wall and ceiling insulator.* 1975

BS 4853: *Specificationfor tensional steel strapping.* 1989

BS 4868: *Specificationfor profiled aluminium sheet for building.* 1972

BS 4872: *Specification for approval testing of welders when welding procedure approval is not required.* Part 1: *Fusion welding ofsteel (T).* 1982

BS 4872: *Specification for approval testing of welders when welding procedure approval is not required.* Part *2: TIG or MIG welding ofaluminium and its alloys.* 1976

BS 4873: *Specificationfor aluminium alloy windows.* 1986

BS 4921 : *Specificationfor sheradized coatings on iron and steel.* 1988

BS 5080: *Structuralfixings in concrete and masonry.*

Part 1. *Method oftestfor tensile loading.* 1993

Part 2. *Method ofdetermination ofresistance to loading in shear.* 1986

BS 5215: *Specification for one-part gun grade polysulphide basedsealants.* 1986

BS 5241 : Rigid polyurethane (PUR) and polyisocyanurate (PIR) foam when dispensed or sprayed on a construction site. Part 1 : *Specification for sprayed foam thermal insulation applied externally.* 1993

BS 5247: *Code ofpracticefor sheet roof & wall coverings,* Part 14: *Corrugatedasbestos-cement.* 1975

BS 5262: *Code ofpracticefor external renderings.* 1991

BS 5270: *Bonding agentsfor use with gypsum plasters & cement,* Part 1 : *Specification for polyvinyl-acetate (PVAC) emulsion bonding agents for indoor use with gypsum building plaster.* 1989

BS 5350: *Methods oftestfor adhesives,*

Group A: Adherants (Parts A1 & A2),

Group B: Adhesives (Parts B1, B2, B4, B5, B8 & B9),

Group C: Adhesively bonded joints. Mechanical tests (Parts C1, C3, C4, C5, C6, C7, C9, C10, C11, C12, C13, C14, C15),

Group D: Adhesively bonded joints. Environmental tests (Part D4),

Group E: Sampling & analysis oftest data (Parts E1 & E2). 1988-91

BS 5368: *Methods of testing windows*

Part 1: *Air permeability test.* 1976 (1985).

Part 2: *Watertightness under static pressure.* 1980. (1986)

Part 3: *Wind resistance tests.* 1978 (1985).

BS 5375: *Method for evaluation of general purpose chloroprene rubber (CR).* 1992

BS 5385: *Wall and floor tiling,* Part 2: *Code of practice for the design & installation of external ceramic wall tiling & mosaics (including terra-cotta and faience tiles).* 1990

BS 5390: *Code ofpracticefor stone masonry.* 1984

BS 5427: *Code ofpractice for use ofprofiled sheeting for roof and wall cladding on buildings.* (to be published)

BS 5534: *Slating and tiling.* Part 1: *Design.* 1978 (1985).

BS 5599: *Specification for hard anodic oxide coatings on aluminium for engineering purposes.*

BS 5628: *Code ofpracticefor use ofmasonry.*

Part 1: *Structural use of unreinforced masonry.* 1992.

Part 2: *Structural use ofreinforced & prestressed masonry.* 1985.

Part 3: *Materials & components, design and workmanship.* 1985.

BS 5642: *Sills & copings*

Part 1 : *Specificationfor window sills ofprecast concrete, cast stone, clayware, slate & natural stone.* 1978.

Part 2: *Specificationfor copings ofprecast concrete, cast stone, clayware, slate and natural stone.* 1983

BS 5838: *Specificationfor dry packaged cementitious mixes,*

Part 1: *Prepacked concrete mixes.* 1980.

Part 2: *Prepacked mortar mixes.* 1980

BS 5889: *Specification for one-part gun grade silicon-based sealants.* 1989

BS 5950: *Structural use ofsteelwork in building.*

Part 2 : *Specification for materials, fabrication and erection: hot rolled sections.* 1985

Part 6: Code of practice for design of hight gauge profiled steel sheeting

Part 8: *Code ofpracticefor fire resistant design.* 1990.

BS 5980: *Specificationfor adhesivesfor use with ceramic tiles & adhesives.* 1991

BS 6073; *Precast concrete masonry units*

Part 1 : *Specificationfor precast concrete masonry units,*

Part 2: *Method for specifying precast concrete masonry units.* 1981

BS 6093: *Code ofpractice for the design of joints andjointing in building construction.* 1993

BS 6105: *Specification for corrosion-resistant stainless steel fasteners.* 1981

BS 6161: *Methods of test for anodic oxidation coatings on aluminium and its alloys* (in 19 parts), Parts 1-19. 1985-93

BS 6 180: 1982: *Code ofpractice for protective barriers in and about buildings.* 1982

BS 6206: *Specification for impactperformance requirements for flat safety glass & safety plastics for use in buildings.* 198 1

BS 62 13: *Guide to selection ofconstructional sealants.* 1992

BS 6265: *Specification for resistance seam welding ofuncoated and coated low carbon steel.* 1991

BS 6270: *Code of practice for cleaning & surface repair of buildings,* Part 1: *Natural stone, cast stone & clay & calcium silicate brick masonry.* 1982

BS 6319: Parts 1-12: *Testing of resin & polymer/cement compositions for use in construction.* 1983- 1993

BS 6399: Part 1: 1984: *Code ofpractice for dead and imposed loads.* 1984

BS 6399: Loading for buildings Part 3: 1988: *Code ofpractice for imposed roof loads.* 1988

BS 6432: *Methods for determining properties of glass fibre reinforced cement material.* 1984.

BS 6457: *Specificationfor reconstructed stone masonry units.* 1984

BS 6463 : *Quicklime, hydrated and natural calcium carbonate,*

Part 1 : *Methods ofsampling,* 1984.

Part 2: *Methods ofchemical analysis.* 1984.

Part 3: *Methods of test forphysicalproperties of quicklime,* 1987.

Part 4: *Methods for test for physical properties ofhydrated lime and lime putty.* 1987

BS 6477: *Specification for water repellents for masonry surfaces.* 1992

BS 6496: *Specification for powder organic coating for application and stoving to aluminium alloy extrusions, sheet and preformed sections for external architectural purposes, and for the finish on aluminium alloy extrusions sheet and preformed sections coated with organic coatings.* 199 *1*

BS 6536: *Specification for continuously hot dip aluminium/silicon coated cold reduced carbon steel sheet and strip.* 1985

BS 6649: *Specification for clay & calcium silicate modular bricks.* 1985

BS 6561 : *Specificationfor zinc alloy sheet and stripfor building.* 199 1

BS 6586: *Rigid polyurethane (PUR)foam produced by the press injection method,* Part 1 : *Specification for PUR foam for insulated panels for transport containers and insulated vehicle bodies.* 1993

BS 6744: *Specification for austenitic stainless steel bars for the reinforcement ofconcrete.* 1986

BS 6830: *Specification for continuously hot dip aluminium/zinc alloy coated cold rolled carbon steelflat products.* 1987

BS 6915: *Specification for design and construction of fully supported lead sheet roof and wall coverings.* 1988

BS 6954: *Tolerancesfor buildings.* 1988 -

BS 7030: *Method for determination of the coefficient of mean linear thermal expansion ofglass.* 1988

BS 7295: *Fusion bonded epoxy coated carbon steel bars for the reinforcement ofconcrete.* Pts 1 & 2. 1990

BS 7373: *Guide to the preparation ofspecifications.* 1991

BS 7412: *Specification for plastics windows made from PVC-U extruded hollow profiles.* 199 1

BS 7413: *Specification for white PVC-U extruded hollow profiles with heat welded corner joints for plastics windows: materials type A.* 1991

BS 7414: *Specification for white PVC-U extruded hollow profiles with heat welded corner joints for plastics windows: materials type B.* 1991

BS 7475: *Specification forfusion welding or austenitic stainless steels.* 1991

BS 753 1 : *Specification for compressed non-asbestos fibre jointing.* 1992

BS 8000: *Workmanship on building sites.*

Part 10: *Code ofpractice forplastering & rendering,* 1989.

Part 1 1: *Code ofpractice for wall and floor tiling:* Section 1 1.1: *Ceramic tiles, terrazzo tiles & mosaics.* 1989. Section 11.2: *Natural stone tiles.* 1990

BS 8110: *Structural use of concrete*

Part 1: *Code ofpractice for construction.*

Part 2: *Code ofpractice for special circumstances.*

Part 3: *Design charts for singly reinforced beams, doubly reinforced beams and rectangular columns.* 1985

BS 8118: *Structural use ofaluminium.*

Part 1 : *Code ofpractice for design.* 199 1

Part 2: *Specification for materials, workmanship, and protection .* 1991

BS 8200: *Code of practice for design of non-loadbearing external vertical enclosures ofbuildings.* 1985

BS 8298: *Code ofpractice for design & installation of natural stone cladding & lining.* 1989

BS EN 204: *Classification of non-structural adhesives for joining of wood & derived timber products.* 1991

BS EN 205: *Test methods for wood adhesives for non-structural applications. Determination of tensi1e shear strength of lap joints.* 1991

BS EN 287: *Approval testing of welders forfusion welding,* Part 2: *Aluminium and aluminium alloys.* 1992

BS EN 288: *Specification and approval of welding procedures for metallic materials,* Part 4; *Welding procedure tests for the arc welding of aluminium and its alloys.* 1992

Bs EN ISO 9000: *Quality management and quality assurance standards.* London: *BSI,* 1994-

BS EN 10130 (replaces BS 1449: Part 1): *Specification for cold ro11ed low carbon steelflat products for cold forming: technical delivery conditions.* 1991

BS EN 10142: *Specification for continuously hot-dip zinc coated low carbon steel sheet and strip for cold forming: technical delivery conditions.* 1991

BS EN 10147 (replaces BS 2989): *Specification for continuously hot-dip coated Structures steel sheet and strip. Technical delivery conditions.* 1992

BS EN 28339 : *Building construction. Jointing products. Sealants. Determination of tensile properties.* (replaces BS 37 12: Part 4). 1991

BS EN 28340: *Building construction. Jointing products. Sealants. Determination of tensile properties at maintained extension* (replaces BS 3712: Part 4). 1991

PD 6512: Part 3: *Guide to the fire performance of glass,* 1987

PD 6472: *Guide to specifying the quality ofbuilding mortars.* 1974

PD 6484 *Commentary on corrosion at bimetallic contacts and its alleviation.* 1990.

DD 88: *Method for the assessment of pot life ofnon-flowing resin composition for use in civil engineering,* 1983

CP 3 Chapter V: Part 2: *Wind loads.* London: *BSI,* 1972

CP 1 18: *The structural use ofaluminium.* 1969

CP 143: *Code ofpractice for sheet roof and wall coverings.*

Part 1: *Aluminium, corrugated and troughed.* 1958.

Part 5: *Zinc.* 1964

Part 15: *Aluminium, metric units.* 1986

Part 16: *Semi-rigid asbestos bitumen sheet. Metric units.* 1974

ENV1991 : *Basis ofdesign and actions on structures* . Eurocode 1 : Part 2. *Actions on structures* (in progress)

ENVl998: *Earthquake resistant design of structures.* Eurocode 8: (in progress.)