



Practical Fixing Guide for Glassfibre Reinforced Concrete (GRC).

**The International
Glassfibre Reinforced Concrete
Association (GRCA)**

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Practical Fixing Guide for Glassfibre Reinforced Concrete (GRC).

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PREFACE

With the rapid growth of technology, the construction industry is gradually moving from 2D to 3D design detailing because of the advantages it offers. In particular, the detailing of GRC products is ideally suited to the use of 3D modelling packages such as Inventor and Solidworks. Both of these packages have been used in the production of this publication. They both deliver a new ground breaking modelling system of functional design. This allows users to move beyond geometric modelling into an environment where they can focus more on the details under consideration.

An accurate 3D model of a GRC cladding system and its fixings can be produced very quickly. This model can then be used to automatically create 2D elevations, plans and sections as well as details of individual panels. Consequently, drafting time is significantly reduced without sacrificing accuracy. Any later changes to the model are automatically reflected in all of the details derived from the previous model.

Both Inventor and Solidworks produce bills of quantities for the GRC panels and associated fixings for costing purposes.

One of the most valuable benefits of using these packages for the detailing of GRC is for its ability to create and test virtual prototypes. Essentially, this enables clash analysis to be carried out ensuring that the GRC panel system fits correctly without any conflicts with supporting structure and interfacing elements, eg glazing, curtain walling etc.

The GRC designer also benefits from working with a modelling package. Once the 3D model has been produced, a finite element analysis (FEA) can be easily carried out to determine deflections and stress distributions under load. Moreover, both Inventor and Solidworks can be used to produce animation, 'fly throughs' and 'fly bys'.

This latest Fixing Guide takes the GRCA's technical publications to a new level. It utilises the latest technology in 3D animation techniques and contains a number of practical examples to illustrate various fixing techniques.

This Guide is in two parts.

Part 1 contains information and illustrations of current fixing methods, in a similar format to the Fixing Guide it is superseding.

Part 2 is a collection of practical examples of fixing methods. This describes each application, provides 3D animations, Autodesk DWF files and other information to enable the reader to interact and fully understand the fixing method(s).

Grateful thanks are given to all members of the GRCA Technical Working Group for their valuable help and determination in producing this first issue of the new Fixing Guide.

Glyn Jones
Chair, GRCA Technical Working Group
March 2010

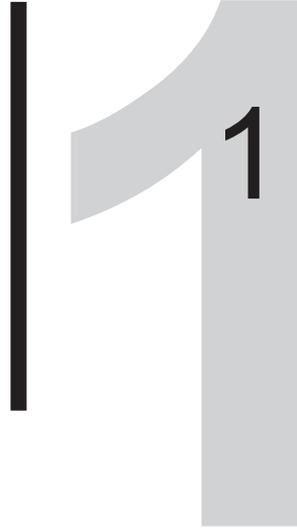
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PART



THEORY & PRACTICE



Glass reinforced concrete (GRC) is a composite material comprising a mixture of hydraulic cement, silica sand, alkali resistant (AR) glass fibres and water. The glass fibres effectively reinforce the mortar mix thereby improving its tensile and flexural characteristics. GRC is a particularly attractive and durable cladding material. It can be moulded into a wide variety of complex shapes and profiles and is ideally suited to the popular fast-track approach of using lightweight, prefabricated cladding panels for the exteriors of modern buildings. The main advantage of GRC panels over the corresponding precast concrete alternatives is the considerable saving in weight. This results in significant savings in the costs of transportation, handling and erection of the panels. If this weight advantage is considered at the design stage, it may be possible to effect substantial economies in the design of foundations and superstructures for high rise building constructions. Other notable advantages of GRC cladding are its durability, chemical resistance, non-combustibility, impact resistance and good sound/heat insulation properties. The main types of GRC in common use, namely, sprayed, premixed, sprayed premixed and self-compacting are fully described in the companion publication 'Practical Design Guide for GRC using limit state theory' produced by the GRCA.

There are many advantages to be gained by having early design co-ordination between the Architect, Structural Engineer and GRC Cladding Designer to identify potential problems. Whenever possible, the glazing/curtain walling specialist should also be involved in these co-ordination discussions to advise on interface issues.

Cladding systems should be able to accommodate normal movements of the building structure. The weights and disposition for the supports for GRC cladding panels are paramount in assessing cladding-structure interaction. Movements due to temperature, moisture changes and shrinkage in both structure and serviceability, deflections of beams and slabs, together with the elastic shortening of columns in the structure could have detrimental effects on the cladding. Due consideration should, therefore, be given to the various methods of alleviating these potential problems. The Centre for Windows and Cladding Technology has produced a series of three Technical Notes (TN55, RN56 and TN57) covering the above issues of designing for movement and load transfer during the service life of the cladding. Another useful reference called 'Aspects of Cladding' published by the Institution of Structural Engineers provides important information about various aspects of different cladding materials, including GRC. Other relevant references are listed at the end of this publication.

This manual is intended to explain and illustrate acceptable methods of fixing various forms of GRC panels to a building or other structure and providing fixings for lifting/handling. The basic principles of design are outlined and related to the practicabilities of ensuring adequate tolerances to allow for erection and the subsequent, combined movements of the panels and supporting structure. Illustrations of several different types of fixings that are in common use or gaining favour are given, together with information about the materials used to manufacture them. Particular reference is made to the need to isolate materials which might give rise to galvanic corrosion, if they were allowed to be in direct contact with each other. General details of the widely used GRC stud frame type of construction are also illustrated, together with recommendations on how to fix the GRC facing to the stud frame.

Finally, in Part 2 of this publication, details of several practical fixing systems are presented to illustrate typical examples of securing GRC cladding panels to the supporting structures. They are not presented in any particular order or merit and are only intended to give general guidance. Many of them are based on parts of actual GRC cladding contracts by kind permission of GRC manufacturers listed in the Acknowledgements section of this Guide.

2

FUNCTIONS OF FIXINGS

The main functions of fixings for GRC cladding panels are as follows:

- (a) to secure the cladding panels to the building for the life of the panels and/or building,
- (b) to allow translational and rotational movements to occur between individual panels and between the panel(s) and supporting structure whilst maintaining waterproofing at the joints,
- (c) to provide sufficient adjustment to accommodate normal constructional inaccuracies in combination with the anticipated movements referred to in (b) above,
- (d) to maintain integrity of support and restraint under all conditions of exposure (impact, vibration, wind, fire, etc.) by minimising local concentrations of stress in the GRC,
- (e) to provide lifting points for the cladding during manufacture, handling and erection,
- (f) to ensure that forces transmitted through the fixings are distributed over as wide an area of GRC as possible,
- (g) to utilise the full strength properties of the GRC by providing supports at the base of the panels and lateral restraints at both the top and bottom of the panels.

NOTE

Fixings for lifting should have F of S of at least 8 to 10

The movements in (b) above can be difficult to quantify. However, it should be possible to make conservative estimates of the magnitudes and directions of these movements for the purposes of designing the fixings and joint sealants.

If remediation to a fixing, or fixings, becomes necessary, either in the factory or on site, the repaired fixing(s) should satisfy all of the above requirements without exception.

NOTE

GRC cladding panels must not be over-fixed as this invariably leads

GRC cladding panels should not be 'over-fixed' as this can result in detrimental cracking of the panel. The term 'over-fixed' does not necessarily limit the number of fixings e.g. four fixings for rectangular panels. It really means that the panel must be free to move and/or rotate at each support as detailed by the designer. This principle is illustrated in Section 4.3 of this publication.

3

TYPES OF CLADDING PANELS

At an early stage, the cladding designer must decide which form of GRC construction to use in order to satisfy the performance requirements. This choice is closely related to the production method and materials as well as the fixing method(s) to be used.

There are basically three main types of GRC cladding, namely ribbed panel construction, sandwich panel construction and stud frame construction. General descriptions of these different types are given below.

3.1 Ribbed Panel Construction

Flat, rectangular (or square) pieces of GRC are only used for very small areas of cladding, eg roof tiles. Ribs or corrugations are required to strengthen and stiffen the panel if it is to be used for larger cladding panels. This strengthening ensures

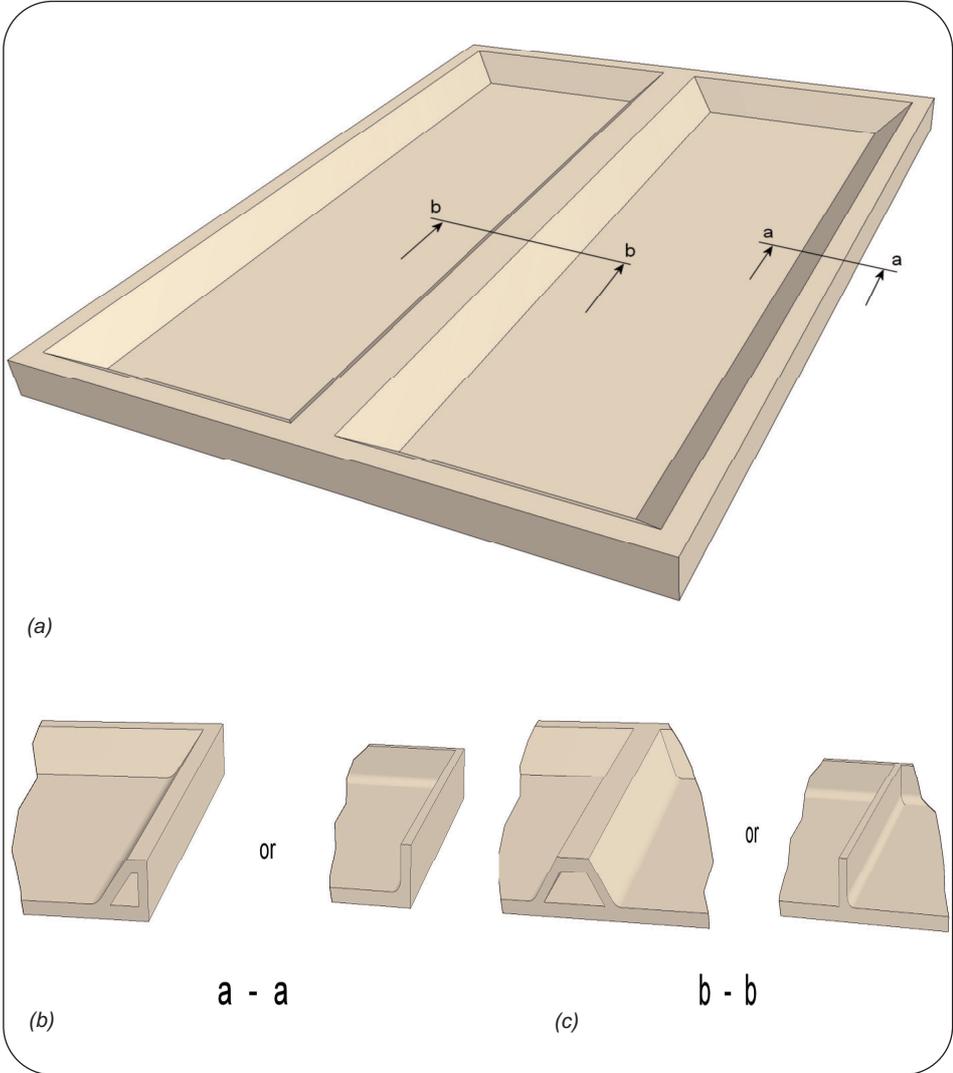


Figure 3.1 - Types of stiffening ribs (edge & internal)

that the panel is not overstressed when subjected to the action of wind and/or seismic forces. Serviceability requirements, usually deflections, are satisfied by virtue of the stiffening effects of the ribs (Figure 3.1a).

A rib is nearly always provided along all external edges (Figure 3.1b) to provide edge stiffening which effectively controls the tendency of the flat panel to bow after manufacture. These edge stiffenings also provide flat return surfaces for the joint sealant to adhere to. Internal ribs reinforce the facing of the panel and are usually formed using a polystyrene or thin GRC former (Figure 3.1c). They can also be formed into the shape of the perimeter ribs as indicated in Figure 3.1c. The limit state design of ribbed panels is adequately covered in the GRCA's companion publication entitled 'Practical Design of GRC Cladding Panels'.

When cast-in sockets are used to anchor the panel(s) to the support structure, it may be necessary to encapsulate the socket in a piece of shaped premix as indicated in Figure 3.2. This is to ensure good compaction of the GRC material

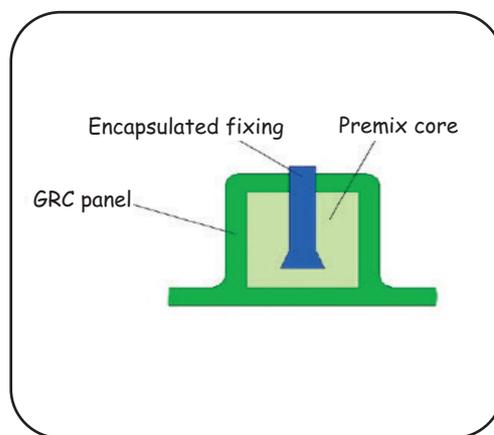


Figure 3.2 - Encapsulated Fixings

NOTE

It is imperative that damage to the permanent fixings is avoided. The encapsulated fixing should be proud of the back face of the GRC panel to avoid pull-out damage during tightening of the connection during fixing.

around the socket. Lifting points can be formed in much the same way. The panel must not be lifted from the permanent fixing points as this risks causing damage to them. Figure 5.2 indicates minimum edge distances for encapsulated fixings.

3.2 Sandwich Panel Construction

Sandwich panels are constructed with two outer skins of GRC separated by a lightweight insulating core. The two GRC skins are normally connected around the edges of the panels by a GRC edge return, and therefore the GRC completely encapsulates the lightweight core. This is termed 'box-type' sandwich construction. Both the front and back skins of GRC are typically between 10 to 15 mm thick (Figure 3.3).

Much less common is the 'bonded' sandwich construction shown in Figure 3.3. Here, the foam infill is much stiffer and becomes a structural element, in that it is required to transmit shear stresses between the external skins.

Sandwich construction is very efficient in load carrying capacity and stiffness, as the GRC is positioned in the regions of maximum stress (in the maximum tensile and compressive faces). Sandwich construction is useful in specific circumstances, but it is not widely used in GRC cladding panel construction today. There is a high risk of differential thermal and moisture movement occurring between the outer and inner faces of a sandwich panel, This can give rise to bowing and high localised stresses, if freedom of movement is not allowed by the shape of the panel and/or the panel fixings.

It is advisable to only manufacture flat sandwich panels thereby avoiding problems associated with temperature gradients, moisture movements and shrinkage

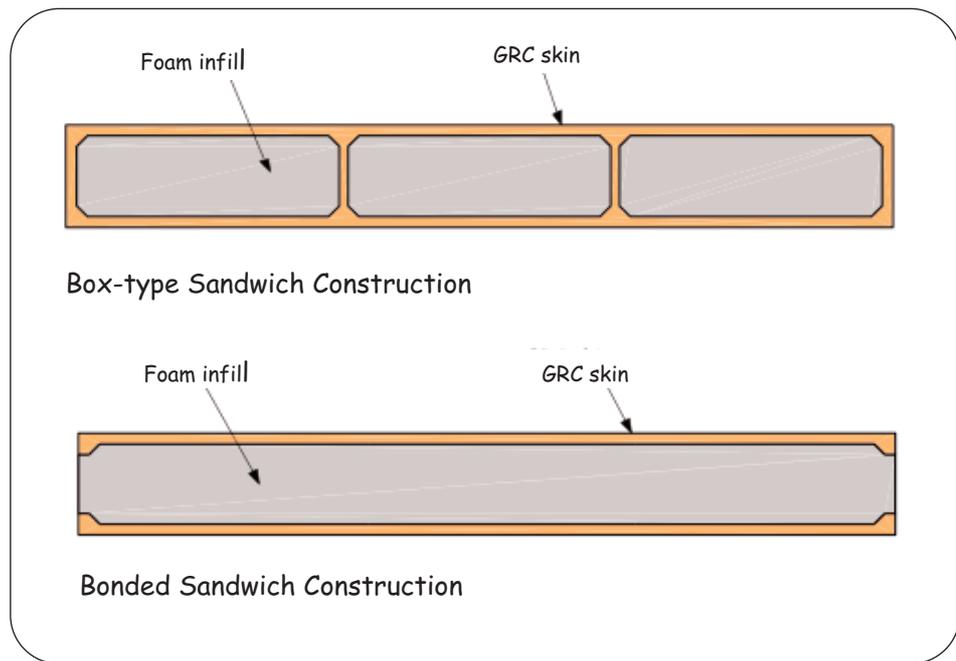


Figure 3.3 - Sandwich type construction

stresses. Figure 3.4 shows the intrinsic shapes of panels that **should not be used** for sandwich construction. It is recommended that flat sandwich panels should not have an area greater than 6.5 m² (eg 3.6m x 1.8m).

One defect that is often found in box-type sandwich construction is that of so-called 'balling' of glass fibre in and around the junctions of the cross ribs and outside faces of the GRC.

Another difficulty, with this same type of panel, is the ingress of water through cracks in the external face. This can saturate the foam formers inside the panels with devastating effects. Freezing of this water can cause parts of the GRC facing to break off.

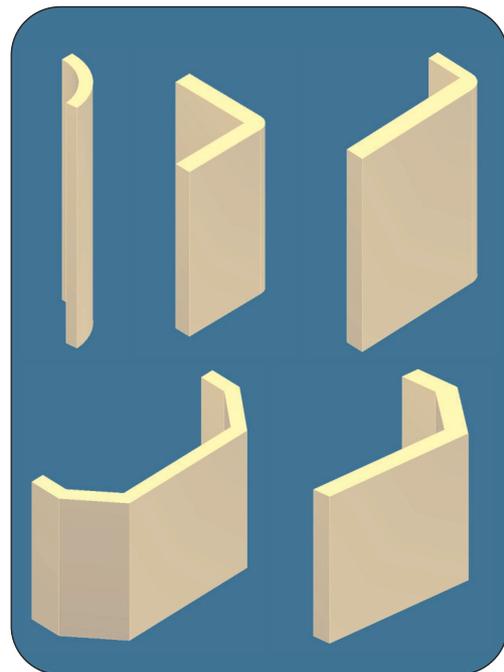


Figure 3.4 - Shapes not to use

Finally, great care should be taken to avoid reductions in the thickness of the outside face of the sandwich panel during manufacture. This is caused by applying too much pressure on top of the foam core or by disturbing it in some way.

Sandwich panel construction is no longer a popular form of GRC cladding construction, mainly because of the likely problems described above.

The insulation requirements of a GRC cladding construction, specified by the architect, can be provided by single skin, stud frame construction with insulation secured to the stud frame. This then allows all of the shapes illustrated in Figure 3.4 to be used.

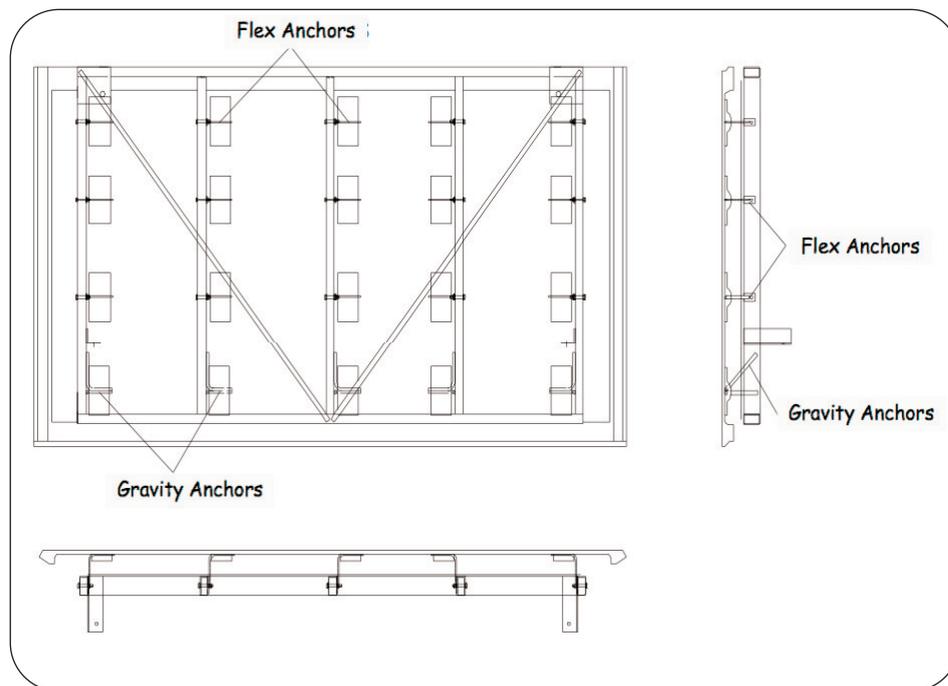
3.3 Stud Frame Construction

A GRC stud frame cladding panel consists of a single skin of GRC attached to a prefabricated frame, usually metal, by means of L shaped flexible anchors (termed flex anchors) and support anchors (known as gravity anchors). Regular spacing of the flex anchors ensures that the effects of wind loading are evenly distributed over large areas of the panels. The flex anchors are for lateral support to the GRC facing whilst allowing some degree of rotation and shrinkage/moisture movement of the GRC. The gravity anchors are positioned along the bottom of the panels and support the self weight of the GRC. This form of construction has gained popularity particularly when very large and generally flat panels are to be made. The stud frame system allows panels of 10-20m² to be manufactured, transported and erected.

Consideration needs to be paid to the material of the frame to avoid risk of corrosion and accordingly stainless steel or suitably treated and protected mild steel are used. This selection may depend on local building regulations.

The wall construction is typically completed by an inner skin of gypsum plasterboard and the space between the outer and inner skins filled with insulating material such as rockwool to give thermal insulation and good fire resistance. Figure 3.5 shows a typical arrangement of a stud frame for a rectangular GRC cladding panel.

Figures 3.6 to 3.8 indicate how unbonded flex anchors and gravity anchors are intended to perform. Note how they all point to the centre of the panel to alleviate



NOTE
All gravity and flex anchors point towards the centre of the panel to allow free shrinkage.

Figure 3.5 - Typical arrangement of GRC stud frame

adverse shrinkage stresses. The flex anchors allow vertical and horizontal shrinkage of the cladding panel. Vertical shrinkage is accommodated by rotation of the flex anchors, by virtue of using a hand tight, lock nut arrangement, whilst horizontal shrinkage is allowed by the debonding sleeve placed on the flex anchor before bonding it to the face. The self-weight of the panel is supported solely on the fixed gravity anchors which are also sleeved to allow horizontal shrinkage of the GRC towards the centre of the panel. Gravity anchors behave as a strut and tie system to support the weight of the panel (Figure 3.8).



Figure 3.6 - Stud frame fabricated from rectangular hollow sections

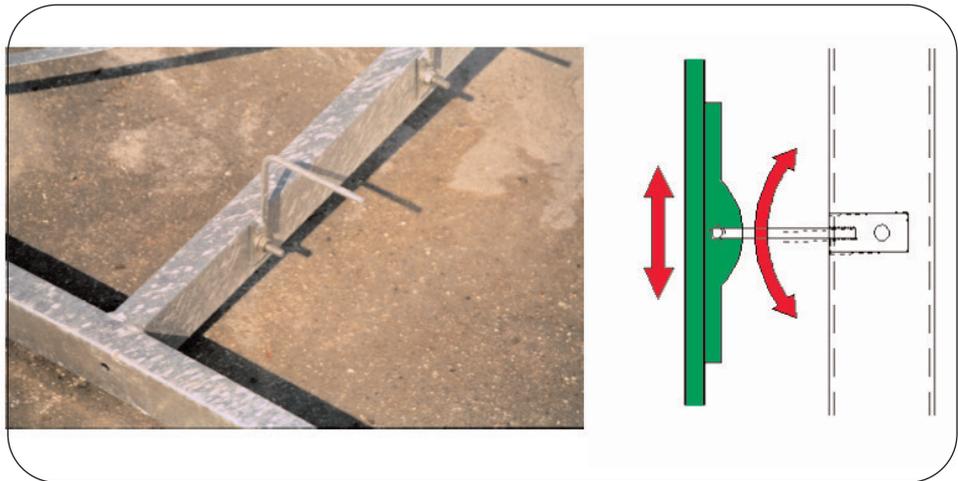


Figure 3.7 - Typical flex anchor indicating degrees of freedom

NOTE
All flex and gravity anchors should be fitted with debonding sleeves prior to constructing the bonding pads.



Figure 3.8 - Typical gravity anchor acting as a strut and tie system

If the stud frame is to be galvanised, the cross ties in Figure 3.6 would be best fabricated from threaded, stainless steel bars, bolted to steel angles welded to the stud frame. These bars are fitted after the stud frame has been galvanised and protected with isolating sleeves to avoid bimetallic corrosion, as described in Section 8. An alternative arrangement of steel flats welded to the frame are not as good because they are prone to distortion during the galvanising process.

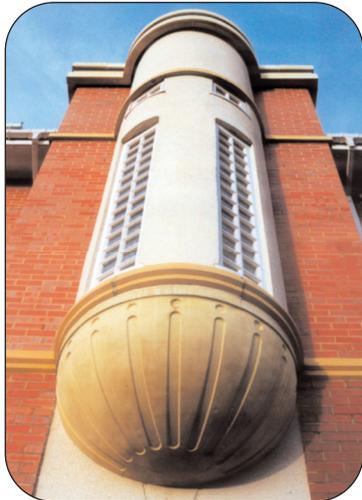


Figure 3.9 - GRC stud frame construction used for globe shaped architectural feature

The architectural feature shown in Figure 3.9 was formed using a triangulated, steel stud frame with adjustable, debonded flex anchors. This frame was bolted to a semi-circular, reinforced concrete landing slab through preformed holes in the slab. This form of construction was chosen to allow the complex movements of the GRC due to shrinkage, temperature and variations in moisture content to occur without causing distress to the GRC.

Stud frames often simplify the way in which such constructions are handled, transported and fixed on site. In this case, the stud frame had three levelling screws to facilitate full adjustability of the construction from the underside of the slab.

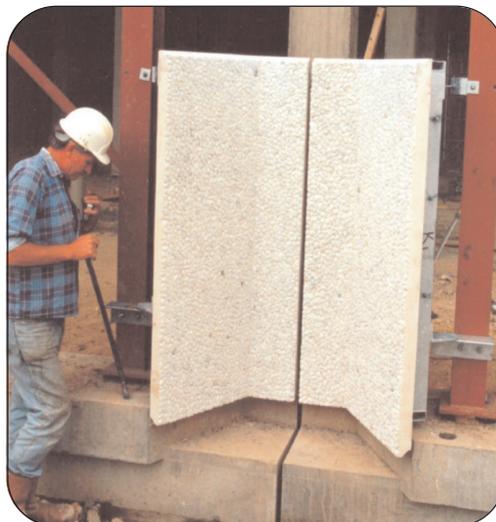


Figure 3.10 - GRC stud frame panels with exposed aggregate finish

The stud frame construction, shown in Figure 3.10, was one of the first to be constructed in the UK with an exposed aggregate finish. Great care was taken to position the aggregate on the mould prior to spraying the GRC. The stud frames were fabricated from rolled hollow sections and galvanised, as pictured in Figures 3.6 to 3.8. The outside faces of the panels were acid etched immediately after being demoulded.



Figure 3.11 - Curved stud frame panels for portico construction

Unlike sandwich panels, GRC stud frame construction does not have to be flat or limited to relatively small sizes. Extremely complicated shapes can be moulded and more than one GRC facing panel can be bonded to the same stud frame. Figure 3.11 pictures and illustrates a simple, curved GRC stud frame fascia over a main entrance feature. The vertical, outer walls are of GRC box rib construction whilst the roof and inner walls were made from GRP. The composite action between the GRC fascia and supporting galvanised steel stud frame strengthened the construction and facilitated easy demoulding, handling and fixing on site.

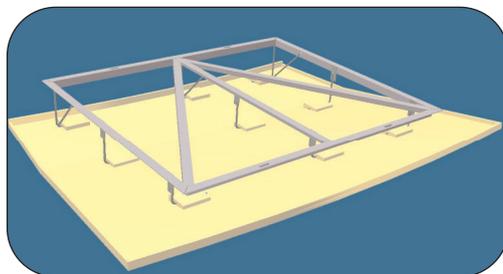


Figure 3.12 - Stud frame construction for canopy (top view)

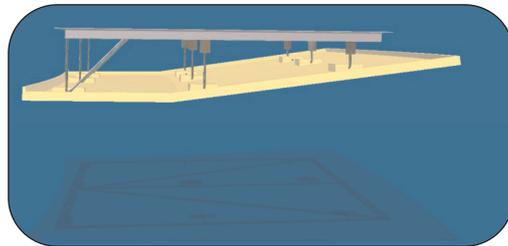


Figure 3.13 - Stud frame construction for canopy (side view)

The construction of the cantilever canopy pictured at the top of the building in Figure 4.13 is shown in Figures 3.12 and 3.13 opposite. The GRC soffit is suspended from the stud frame by means of flex anchors and gravity anchors. In using this type of construction, the gravity anchors must be carefully positioned so that they are at the base of the GRC soffit unit if and when it is lifted into the vertical position during handling and fixing operations. Whilst taking no load when the panel is vertical, each flex anchor supports a proportion of the self weight of the GRC soffit when it is in service. The gravity anchors are under load in all circumstances and also stabilise the construction against wind action in service conditions.

The top GRC panel of the construction is faced-fixed to the stud frame and the fixing points are hidden by small GRC cover plates which can be glued into place. This example of stud frame construction is also featured in Project 9 of Part 1 of this Guide, the animation clearly shows how the canopy is supported on the building.



Figure 3.14 - Large GRC stud frame panel in USA

The use of stud frame construction is often the most economical and preferred method for constructing medium to large panels. Figure 3.14 shows a very large, stud frame panel in USA. A single stud frame can be designed to support several GRC panels with physical joints between them. However, it is serviceability conditions, namely, allowable deflections that tend to govern the maximum size of the stud frame and how many individual panels it can support. Larger stud frame panels tend to require diagonal members to control the resulting deflections.

At the other end of the scale, stud frame construction can often simplify the production and fixing of small panels like those making up the mock corbel shown in Figure 3.15. In this case, the gravity anchor need only be a single U-bar, the same goes for the two flex anchors.

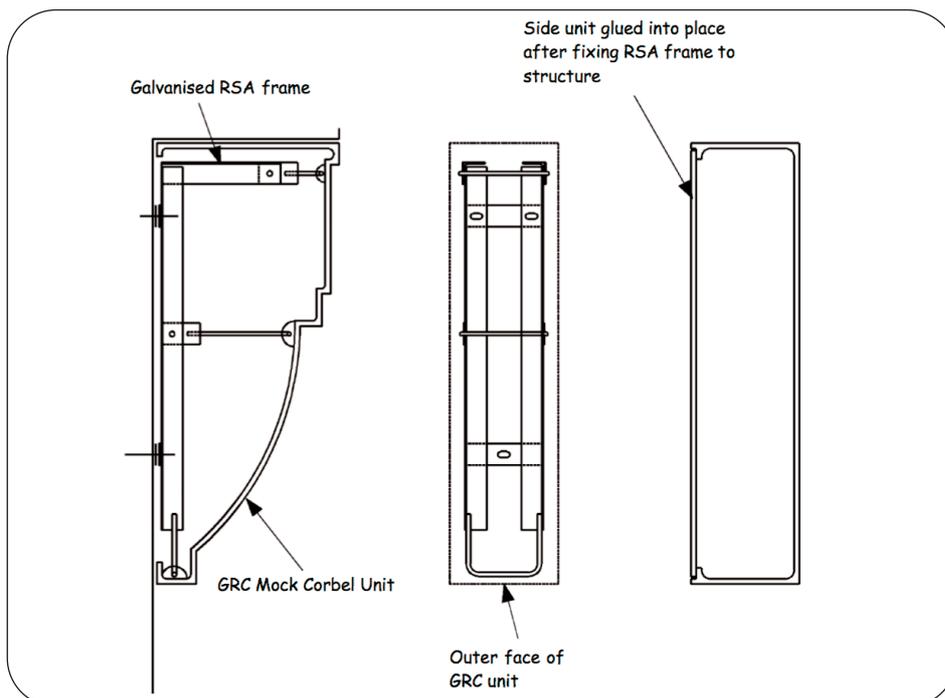


Figure 3.15 - Small scale, stud frame construction for mock corbel

NOTE
 All anchors should point towards the centre of the panel to alleviate adverse shrinkage stresses. When an anchor has to point the other way, sufficient distance must be left between the edge of the bonding pad and the start of any bends in the anchor to accommodate the free shrinkage of the panel.

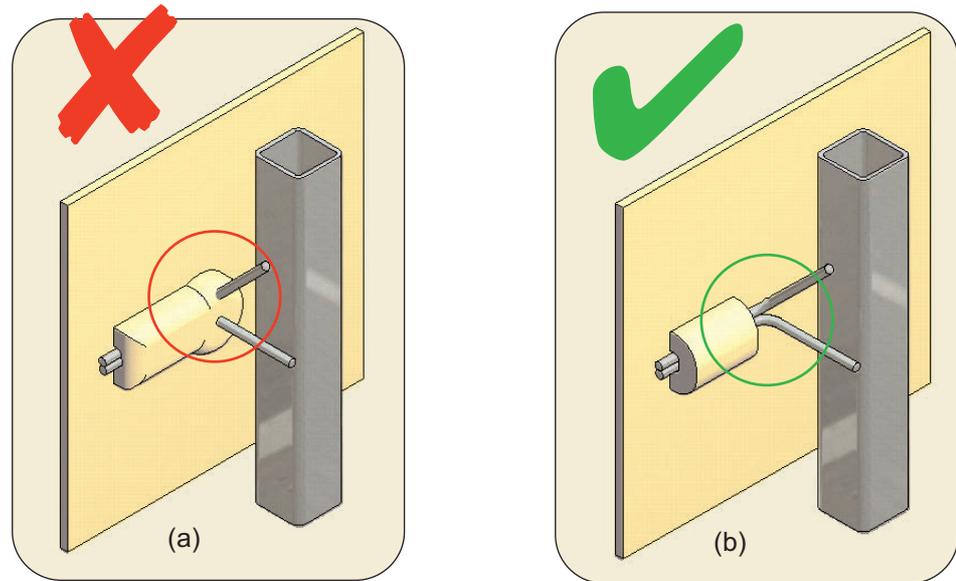


Figure 3.16 - Incorrect and correct way to form bonding pad around a sleeved gravity anchor

Bonding pads around gravity anchors and flex anchors must not impede the free movements of the GRC facing. In Figure 3.16(a), the surplus bonding pad around the bends in gravity anchor will restrict the free movement of the facing. Figure 3.16(b) indicates how the bonding pad should be formed. Care must also be taken to maintain a minimum thickness of GRC around the pad, equal or greater than the thickness of the facing.

All of the anchors, whether they be fabricated from steel bars or steel flats, should be fitted with debonding sleeves to facilitate free in-plane movement of the GRC panel.

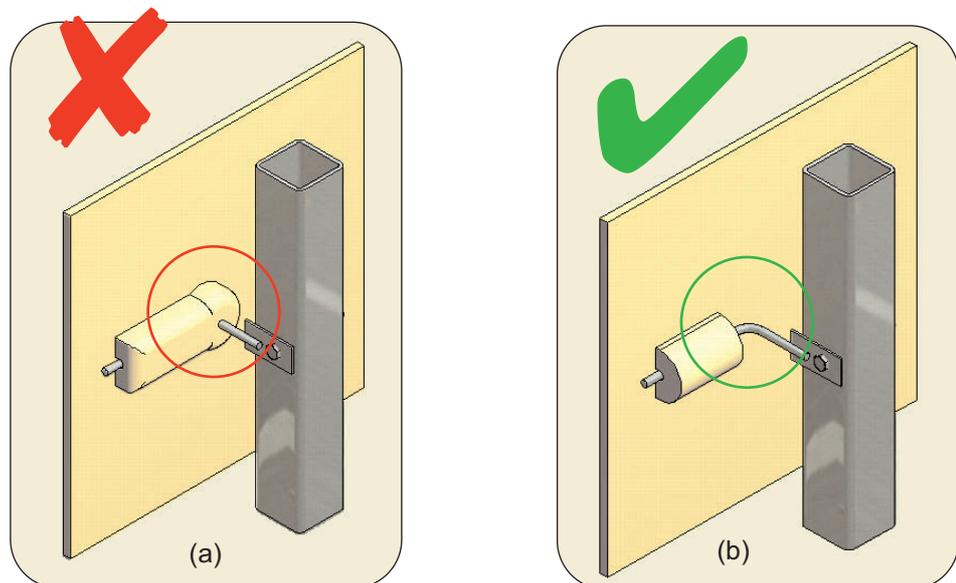
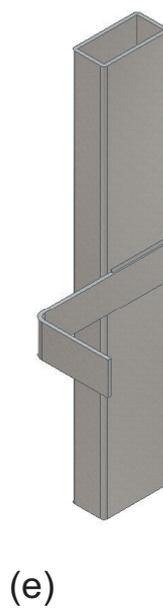
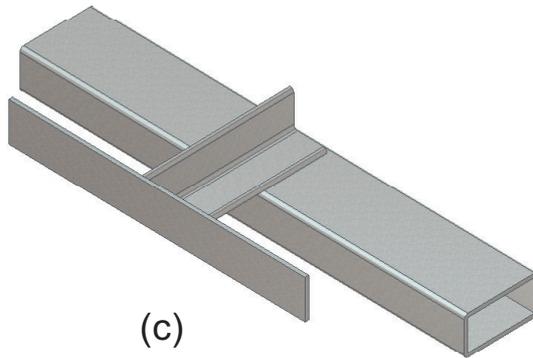
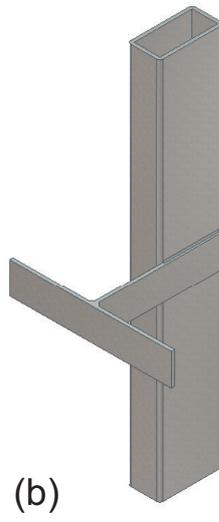


Figure 3.17 - Incorrect and correct way to form bonding pad around sleeved, flex anchor

Various forms of gravity anchors are shown in Figure 3.18. The ones fabricated with flat plate are used for the larger, heavier panels. When the stud frame is fabricated using pultruded sections, the gravity anchors have to be bolted to the frame. One way of achieving this is to weld the gravity anchors to flat plates and then bolt them to the pultruded frame.

Figure 3.19 shows various forms of flex anchors. None of these are intended to support the self weight of the GRC panel.

A brief descriptions of each type of gravity and flex anchor is given below:



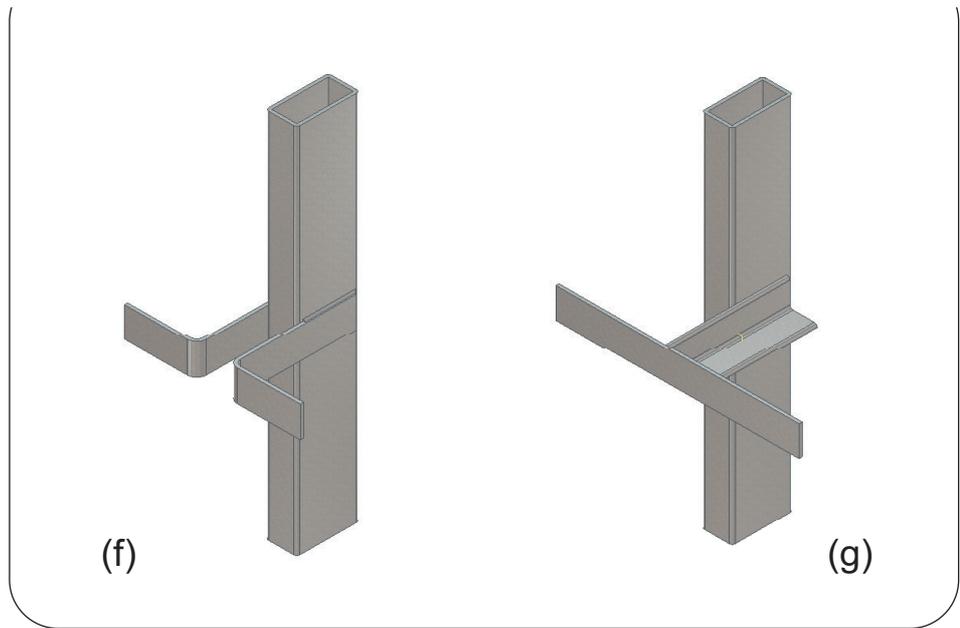


Figure 3.18 - Various forms of gravity anchors (a) to (g)

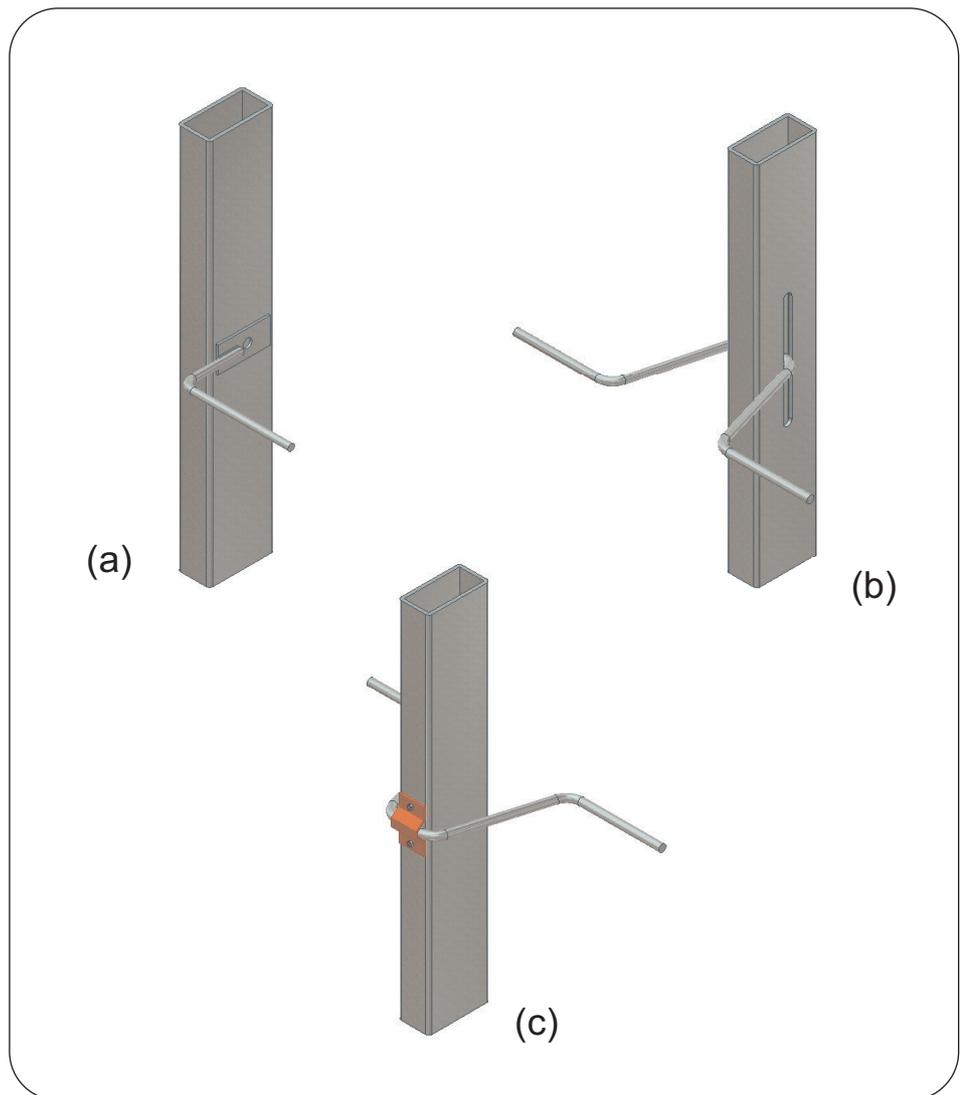


Figure 3.19 - Various forms of flex anchors (a) to (c)

Figure 3.18 - Gravity anchors

- (a) Conventional type of gravity anchor made up of two bent bars welded to vertical steel member of the stud frame. Behaves as a 'strut & tie system'.
- (b) Type of gravity anchor to support large GRC gravity panels. The bending stiffness of the steel flats provide the required support.
- (c) Type of gravity anchor that could be used when it is convenient to weld it to a horizontal, stud frame member.
- (d) Similar to type (a); here the bent steel bars are welded to a steel plate which is drilled with two holes for bolting it to a pultruded section.
- (e), (f) Variations using bent plate welded to vertical steel member.
- (g) Very similar to Type (c) but welded to vertical steel member

Figure 3.19 - Flex anchors

- (a) Conventional flex anchor consisting of a bent bar welded to a steel plate. This is then bolted to a vertical member of the stud frame. A captive nut is sometimes used as these nuts need only be hand tight.
- (b) A specially bent bar is threaded through a vertical slotted hole and rotated through 90 degrees into the position shown. This allows free movement of the bar by vertical and rotational transitions.
- (c) Similar to Type (b) but removes the need for slotted holes. This type can be used when there is only a small distance between the back face of the GRC and front face of the stud frame. If the stud frame is to be galvanised, the captive fitting on the back face of the stud frame must be fixed after the frames and anchors have been galvanised.

The GRC facing in conventional GRC stud frame construction does not have ribs, other than those around its perimeter. Apart from the strengthening benefits, some form of edge return, usually 30mm to 40mm, is required to facilitate waterproofing of the construction.

The required number of flex anchors is governed by:

- (a) the lateral resistance required against wind and seismic actions.
- (b) the spacing of these anchors, both vertically and horizontally, to ensure that the GRC facing is not overstressed in bending.

Similarly, the required number of gravity anchors is determined by the self weight of the GRC facing they support and also the requirements in (a) above.

As an approximate rule-of-thumb, each flex and gravity anchor can be considered to provide a safe, lateral restraint in service of 1 kN when bonded to Grade 18 sprayed GRC. Hence, a stud frame panel with a facing 4m long x 2m high resisting a wind load of 2kN/m², requires a minimum of $(4 \times 2 \times 2/1) = 16$ anchors. Generally, in providing sufficient support for a 15mm thick GRC face in bending, anchors are usually positioned at 600mm centres in both the horizontal and vertical directions. This requires a total of 28 anchors, 7 of which are gravity anchors. Each of these 7 anchors would be required to support a proportion of the self-weight (approximately 50 Kg each in this case).

One way of addressing the inequality between the requirements set out in (a) and (b) above is to increase the spacing of the anchors in the horizontal direction. This is achieved by removing some of the vertical members of the stud frame and providing a system of small ribs in the facing to enhance the bending strength of the GRC. This alternative, hybrid construction (part ribbed and part stud frame construction) can save up to 25% of the cost of the framing and a substantial cost of the anchors, albeit at the relatively small expense of providing a series of small ribs. However, these ribs do increase the weight of the panel, so it is necessary to re-check the load carrying capacity of the reduced number of gravity anchors. If required, additional gravity anchors could be welded to the bottom boom member as illustrated in Figure 3.18.

Figure 3.20 shows the rear view of the conventional stud frame construction described above. The GRC facing only has to span 600mm in both the vertical and horizontal directions. The resulting bending stresses in both the GRC facing and supporting stud frame are generally small.



Figure 3.20 - Rear view of conventional stud frame construction

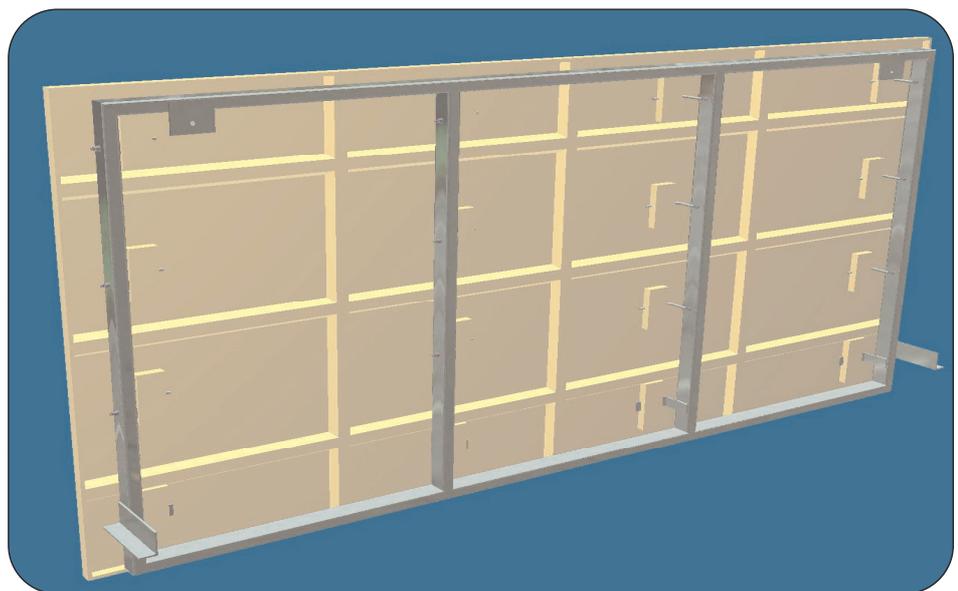


Figure 3.21 - Rear view of hybrid, stud frame construction

Figure 3.21 shows a rear view of the hybrid construction described above. The spacing of the anchors in the horizontal direction is now 1300mm (approx); this

necessitates the introduction of a series of horizontal ribs, as shown, to increase the bending strength of the GRC facing.

It is imperative that the design of any form of stud frame construction is based on reliable test data for the pull-off strength of both types of anchor. The gravity anchors have also to support the self weight of the panel, so the bonding pads around these anchors must also resist a shear load as well as the pull-off load induced by wind loading.

Results of a finite element analysis of the hybrid stud frame panel described above, subjected to a serviceability wind load of 2 kN/m^2 , are shown in Figures 3.22 and 3.23. This method of analysis can be used to great advantage in determining the layout and sizes of ribs to satisfy practical design guide

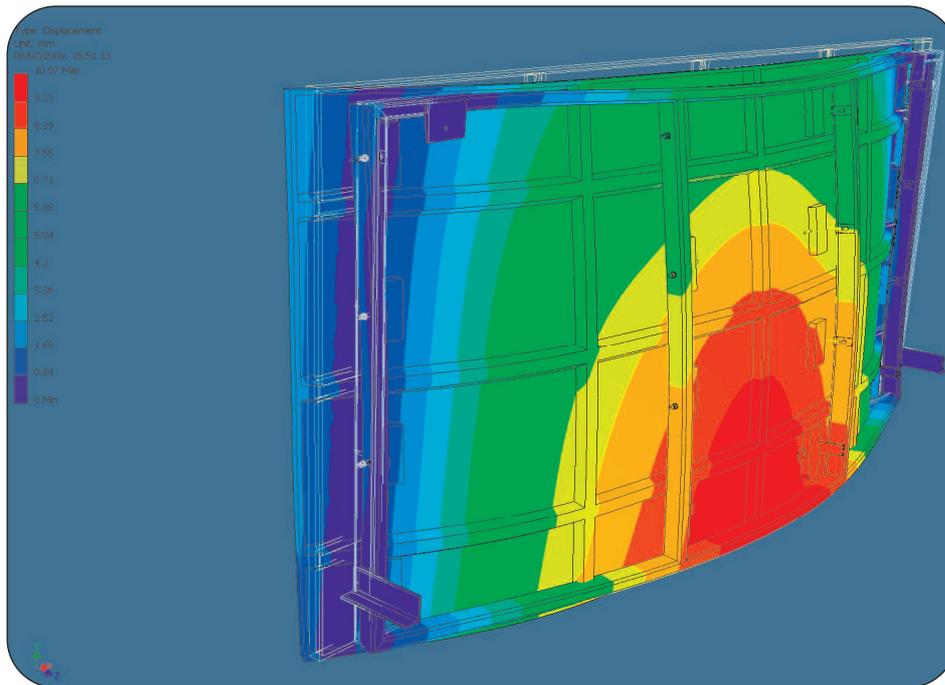


Figure 3.22 - 'Exaggerated' deflections of hybrid stud frame construction

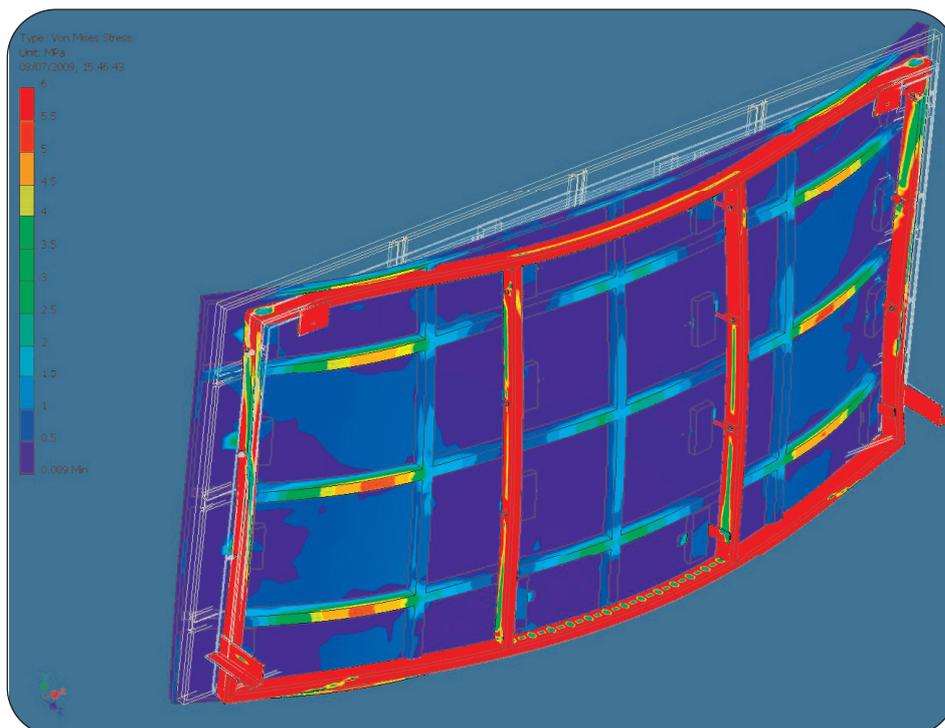


Figure 3.23 - Variation of bending stresses in GRC (disregard steel values)

requirements. In this example, it is apparent that the introduction of another horizontal rib towards the bottom of the panel would reduce both the lateral deflections and bending stresses induced into the GRC panel by the wind loading. In Figure 3.23, the maximum stress level has been limited to investigate the variation of stresses induced into the GRC. Corresponding stresses in the steel stud frame are determined by raising this stress limit to a much higher value.

Another suggestion for developing GRC stud frame construction is to use pultruded material for the frame itself, thereby creating an even more lightweight cladding panel system. Two obvious problems arise, namely, the possible deflection of the frame under load ($E_{\text{steel}} / E_{\text{pultruded}}$ is approx. 10) and its resistance to fire. The deflection of the frame is controlled to a great extent by the in-plane stiffness of the GRC facing to which the frame is bonded. Moreover, diagonal members can also be introduced, as in a conventional truss, to stiffen the frame further. Pultruded material is very flame retardant and flame resistant and should comply with BS 476 Part 6/7. Manufacturers can sometimes, but not always, adjust the contents of the matrix to ensure that the pultruded material meets specified criteria relating to its fire resistance.

3.4 Correct Choice of Panel Type

Choosing the correct GRC panel to use is paramount. Nowadays, sandwich panel construction is not very popular because of the possibility of it cracking due to the effects of temperature differentials, uneven shrinkage and its tendency to bow. It usually comes down to choosing between box rib or stud frame construction. One of these types can nearly always be used in lieu of sandwich panel construction to provide the required insulation and appearance.

Sandwich panel construction should only be used, if at all, for plain, rectilinear panels having an area less than 6.5 m². Figure 3.24 shows what can happen when sandwich panel construction is used incorrectly for curved members.

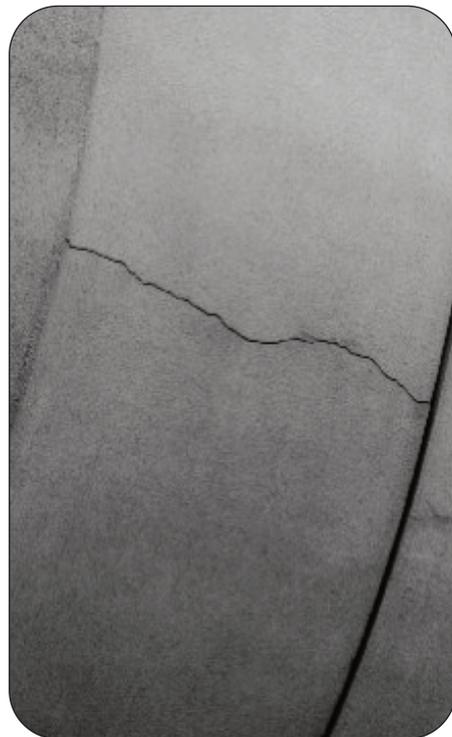


Figure 3.24 - Cracked sandwich panel

Not only was the wrong type of panel used, it was also rigidly fixed to the supporting steelwork behind in six places. Two connections were made at each end with two more in the middle. The crack appeared close to the central pair of fixings. The prognosis is that the panels were damaged during the fixing phase by using the fixings to align the panels. Tightening the two outer pairs probably initiated the crack on the outside face. Similar cracks can be seen on the inside face close to the central fixings. No doubt these were caused by overtightening the central fixings to align the panels. Percolation of rainwater into the cracks and polystyrene cores caused further deterioration. Hindsight is a wonderful thing but it is true to say that stud frame construction should have been used in this case to minimize problems with alignment and bowing. Securing the steel stud frames to the steelwork support system would have been very straightforward.

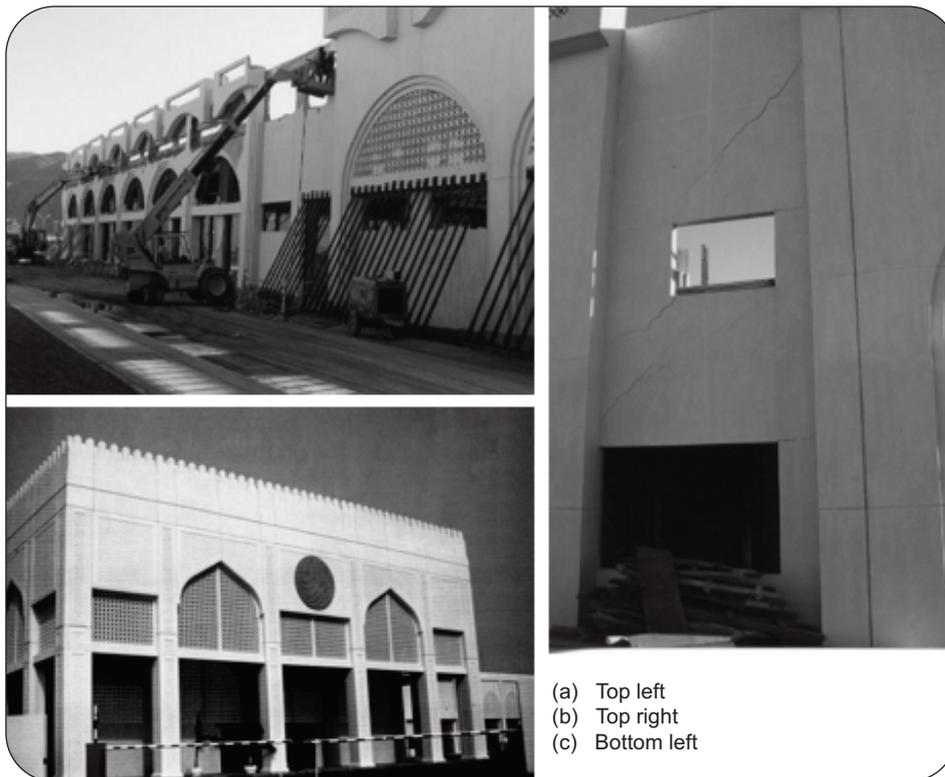


Figure 3.25 - Use of GRC cladding in lieu of conventional precast concrete cladding.

The building pictured in Figure 3.25 demonstrates how the use of lightweight GRC cladding can overcome the detrimental effects of poor ground conditions.

The cladding for this building was specified as conventional reinforced concrete panels (generally about 75mm thick). Soon after a number of these panels had been fixed to the building, deep diagonal cracks began to appear in the panels (Figure 3.25(b)). A large number of acrow props were quickly installed to support the damaged panels and building whilst the cause of the damage was ascertained (Figure 3.25(a)). After further soil investigations on site, it became apparent that the damage to the cladding panels and parts of the structure behind had been caused by differential settlements of the ground.

As part of the remediation works, the cladding was changed to GRC to maintain the appearance of concrete whilst drastically reducing the loads on the foundations. Figure 3.25(c) shows a view of the completed building. Sprayed pre-mix was used to manufacture the sunscreens, whilst a mix of box rib and stud frame constructions was used to manufacture the remainder of the panels.

Clearly, these problems should have been recognised and overcome at the design stage. This example also shows how important it is to choose the correct form(s) of GRC cladding to use on a building founded in variable ground conditions.

4.1 Overview and Design Considerations

In order to produce a safe, efficient and economic fixing system, it is necessary to understand the basic design principles and criteria. The designer should first identify any constraints which might be imposed by conditions on site. Such constraints, if any, may have a significant influence on the choice and detailed design of the fixings. Typical examples of these constraints are problem associated with access, conflict with fixings for other elements, excessive misalignments of support elements and conformance to a demanding programme of works.

GRC panels should not be 'over-fixed' to the structure as this will inhibit shrinkage, moisture and thermal movements and could result in detrimental cracking of the panels. The positioning of fixings is covered in Section 4.3.

The structural behaviour of GRC panels under load should be carefully examined. Fixings are usually provided at each of the four corner points of rectangular, ribbed panels having a span/depth ratio < 4. It is advisable to avoid long horizontal ribbed panels (with span/depth ratio > 4) as bending can cause distress of the GRC in the vicinity of the fixings due to rotational and/or translational movements.

Fixings should also be positioned so as to minimise any permanent stresses which might be induced into the panels. Forces transmitted through the fixings should be distributed over as wide an area of GRC as possible. Adequate bearing areas must also be provided on the supports at the base of the panels to avoid distress to the GRC. Small rectangular panels are often face fixed to the supporting structure. In this case, the fixings at the base of the panel provide vertical support by virtue of their shear resistance. As always, all fixings will be required to provide lateral support.

BS 5606:1990 and BRE Digests 199 and 223 contain important information about inaccuracies to be considered in the design of fixings. Adequate tolerances must be incorporated into the fixing system if it is to perform functions (b) and (c) listed in Section 2. Ideally, all fixings should be easily accessible for adjustment and maintenance, although this is not always possible.

It is important to remember that galvanised fixing components have a finite life which is directly proportional to the thickness of the zinc coating. As a general rule, stainless steel fixings should be used whenever possible because of their high resistance to corrosion. Stainless steel is an obvious choice of material for fixings which are unavoidably inaccessible (positioned out of sight).

Separate fixings should be provided for lifting/handling purposes to avoid possible damage to the permanent fixings.

The total costs of fixings should be carefully considered in the context of the simple balancing equation:

$$\text{Total Cost of Fixings} = \text{Material/Fabrication Costs} + \text{Costs of Installation.}$$

An increase in material/fabrication costs, associated with the use of more expensive and sophisticated fixings, can be balanced against the reduction in costs of installation resulting from savings in time on site. This point should be borne in mind when choosing the type of fixing(s) to be used.

4.2 Development of Design Brief

GRC designers should ensure that they are given a clear design brief at the outset to avoid conflicts and misunderstandings at a later date. This is obviously

influenced by the contractual arrangements preferred by the Client. Five alternative arrangements are illustrated in Figures 4.1 to 4.5.

In Figure 4.1, the GRC fixing team is shown as being employed by the GRC manufacturer. Whilst this is usually the preference of the Client and/or main contractor, most GRC manufacturers in UK prefer the main contractor to employ the fixing team or for the main contractor to fix the cladding. If the method statement produced by the designer is comprehensive and clear, it should be well within the ability of an experienced contractor to undertake the fixing work. GRC manufacturers generally find it difficult to employ their own fixing team because the team cannot be kept busy all the time. However, this arrangement can work if the team has other duties to fall back on.

The preferred arrangement for a GRC designer is usually that shown in Figure 4.3 or 4.4. Here, the designer is directly employed by the one of the design team or the Client. This is ideal for manufacturers tendering for work; they each receive the same tender documents and details upon which to base their bid. With the arrangements shown in Figures 4.1 and 4.2, each manufacturer should produce a tender design, ideally with the help of a designer. This design is often based on very sketchy details. Sometimes manufacturers bidding for work in this situation only have time to price the GRC content and add a percentage to (hopefully) cover the design element. This is not the ideal position for the main contractor either as it invariably results in the submission of a wide spread of bids from the manufacturers.

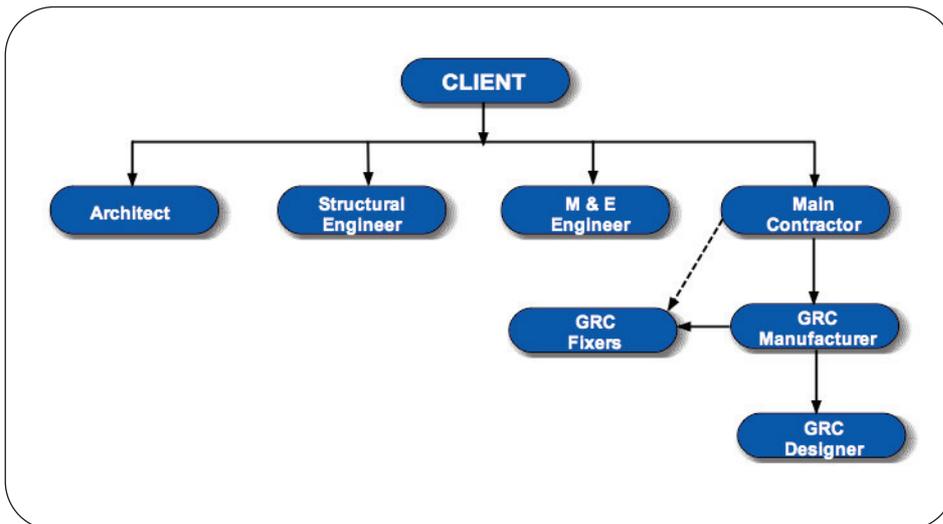


Figure 4.1

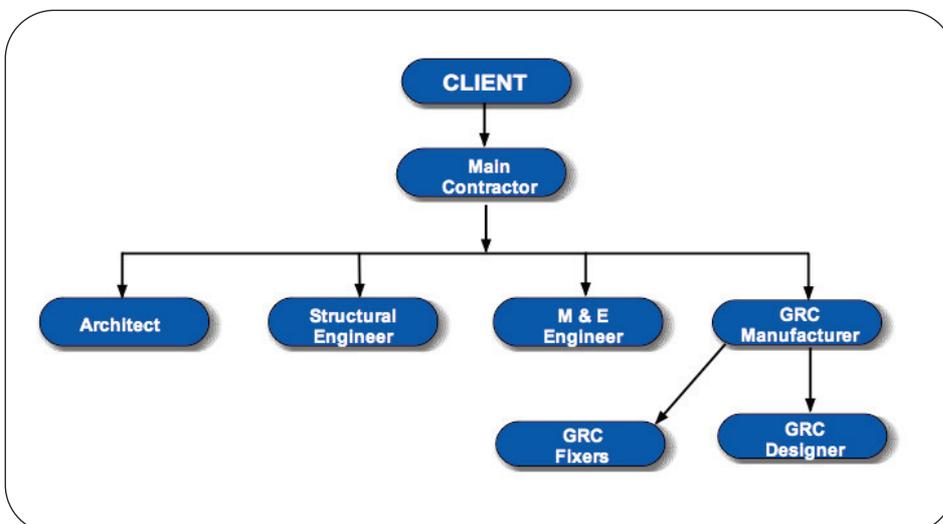


Figure 4.2

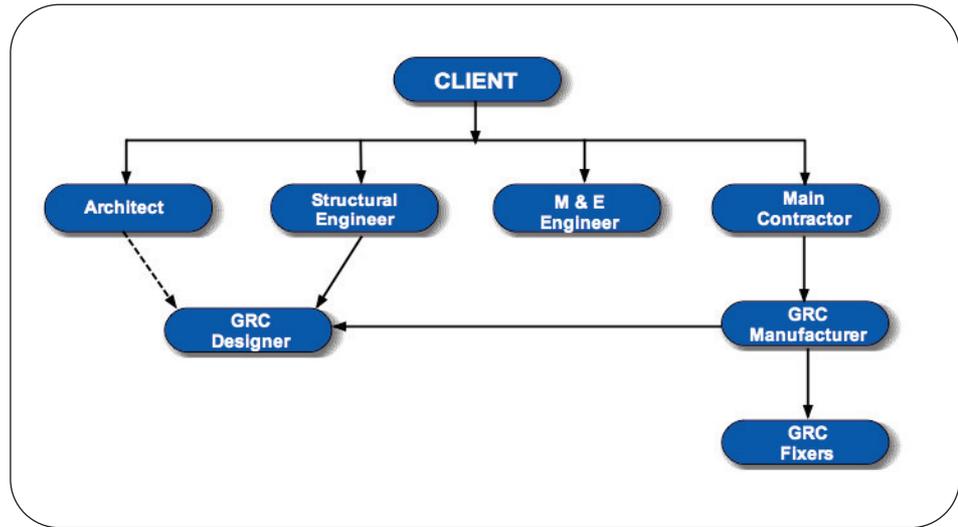


Figure 4.3

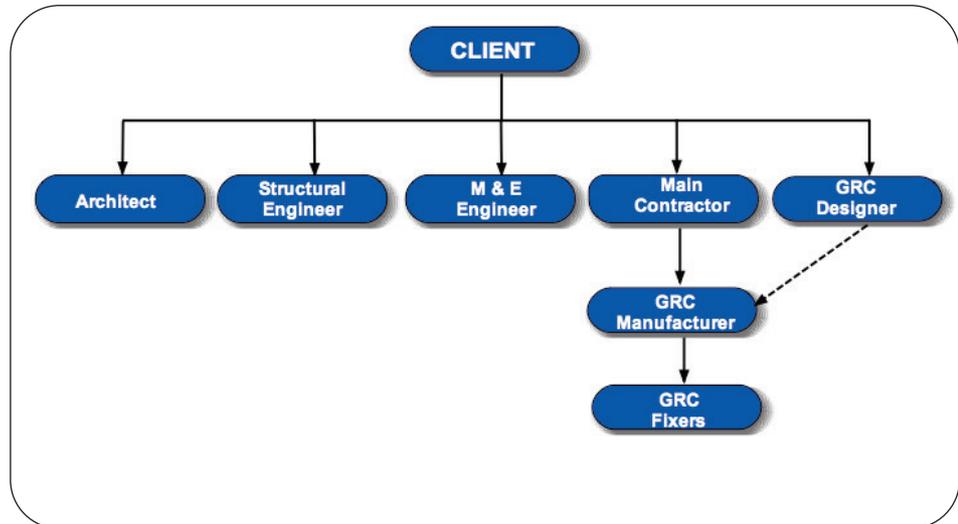


Figure 4.4

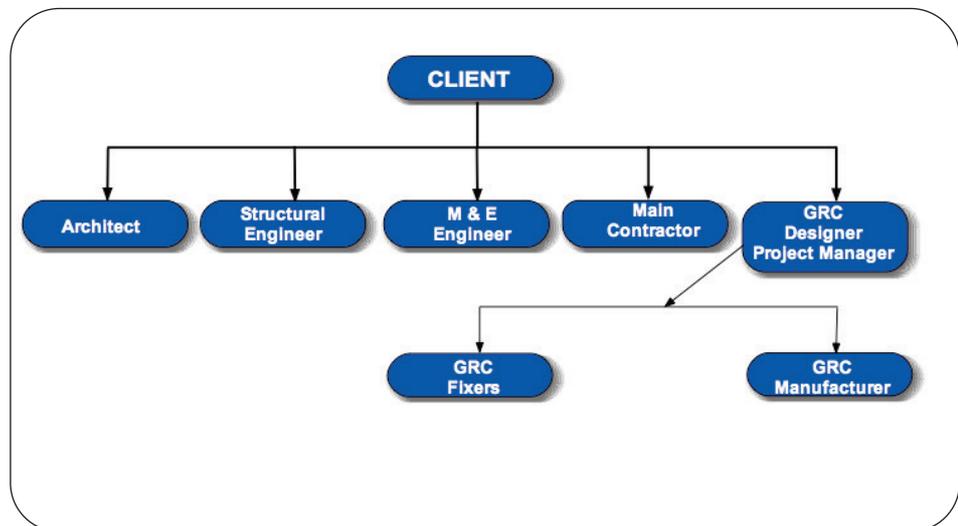


Figure 4.5

Equally, designers in the positions shown in Figures 4.1 and 4.2 are very exposed to receiving unjust criticisms and claims from the manufacturer and/or the main contractor, basically because there is no-one else left to blame.

Figure 4.5 indicates the GRC designer acting as a project manager for the Client. This can work well for both parties but does give the designer far more responsibility acting as the sole point of contact for the Client (or alternatively, the main contractor).

4.3 Positioning of Fixings and Supports

4.3.1 General Considerations

Fixings for GRC cladding panels support the self-weight of the panel and provide lateral restraint against the actions of wind and seismic forces. Vertical support should be provided by seating cleats, at or close to the base of the panels. This ensures that the permanent direct stresses due to self weight are compressive and utilises the full strength properties of the GRC to resist transient imposed loadings. It follows that GRC panels should not be top hung in service as this would obviously induce permanent, direct tensile stresses into the panels. The tensile strength of the panels should be checked for lifting purposes, bearing in mind that it is only a temporary condition.

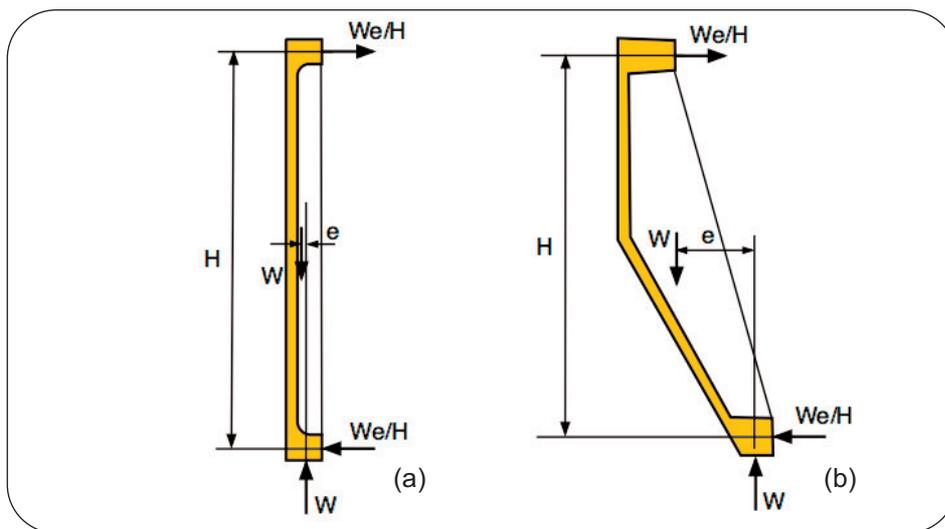


Figure 4.6 - Eccentricity of Self-Weight

In providing support points at the base of the panels, it is good design practice to limit the eccentricity (e) of the self weight (W) from the support point (Figure 4.6 a). This will, in turn, limit the permanent reactions in the top and bottom restraint fixings and hence the bending and shear stresses induced into the panels. Ideally, the eccentricity (e) should be zero, but this is rarely achievable. In vertical panels, the permanent stresses resulting from this eccentricity are usually small. However, when all or part of the panel slopes at some angle to the vertical, as illustrated in Figure 4.6 b, the eccentricity (e) increases and the induced stresses may become significant.

Clearly, the position of the centre of gravity governs the way in which a GRC panel is lifted, transported and manoeuvred on site, with health and safety being the prime considerations.

The suggested positioning of fixings and supports for rectangular box rib panels are shown diagrammatically in Figure 4.7, 4.8 and 4.9 using the following conventions:

All supports have lateral restraint, but have varying degrees of in-plane restraint.

- Fixed support
- Support with no in-plane restraints
- Support with in-plane freedoms in a horizontal direction
- Support with in-plane freedoms in a vertical direction

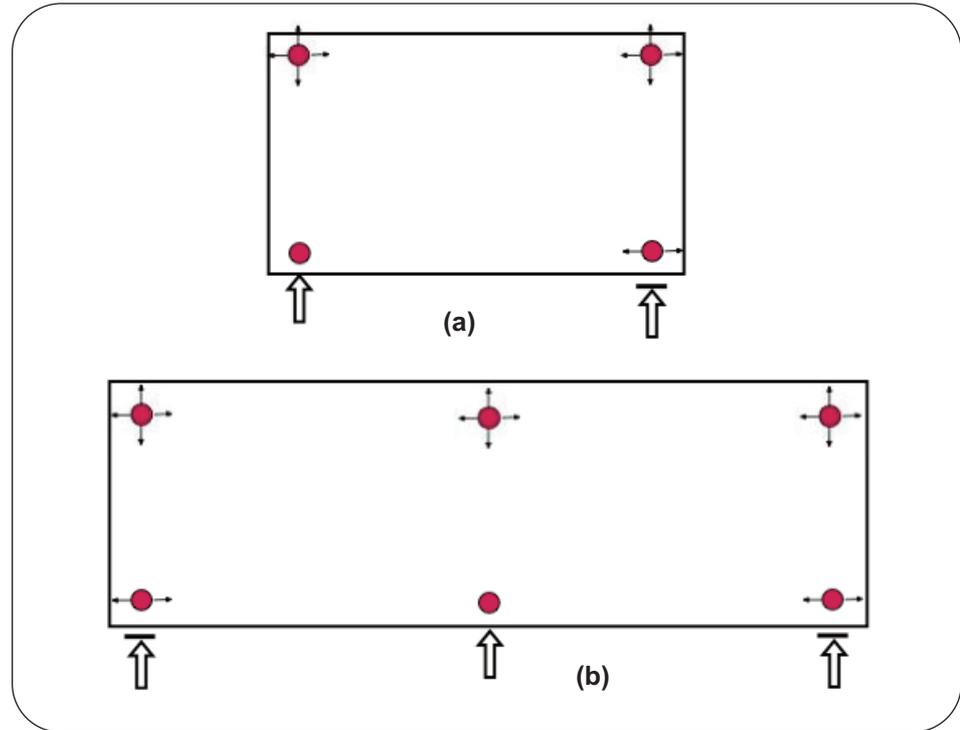


Figure 4.7 - Rectangular Panels

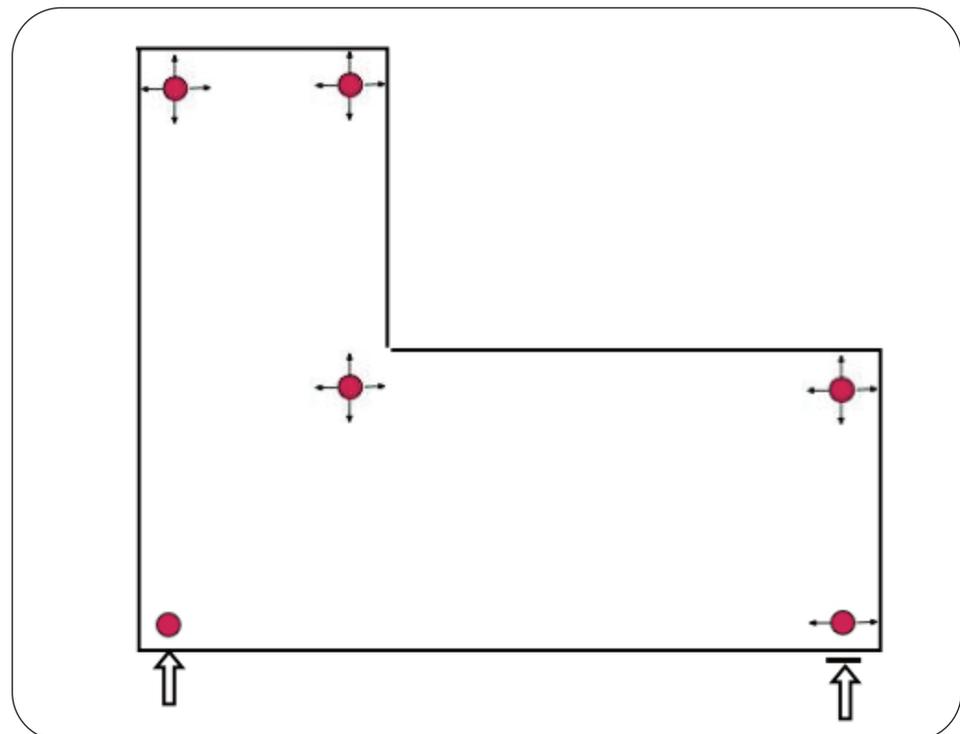


Figure 4.8 - L-shaped panel

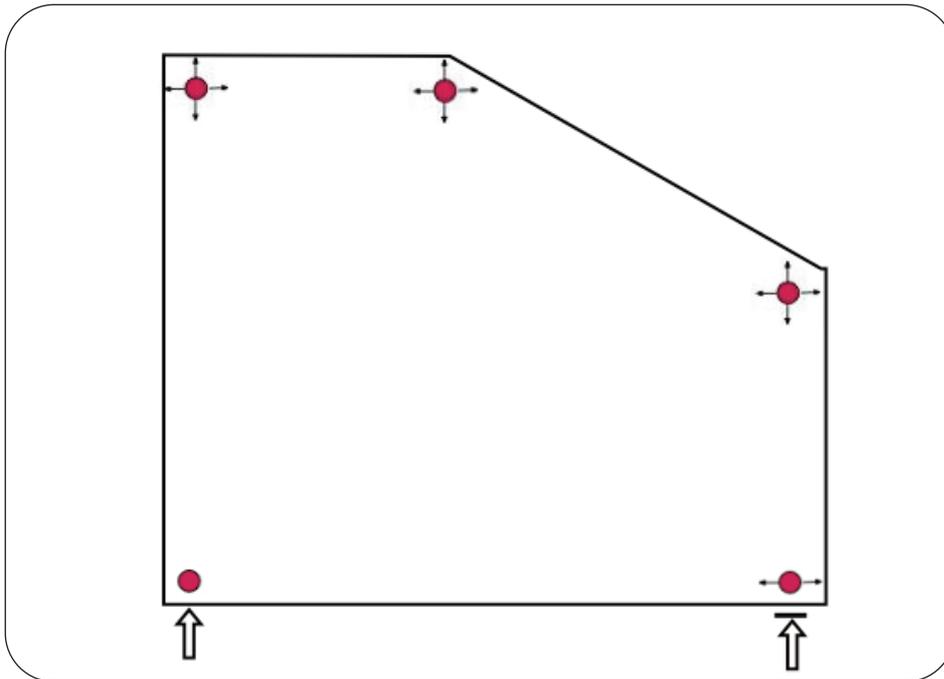


Figure 4.9 - Rectangular panel with corner removed

Figure 4.7(a) shows the conventional fixing details for a rectangular, box ribbed panel; all fixings have lateral restraint and a degree of rotational freedom in any direction. One bottom fixing is fully fixed against in-plane movement. The other base fixing has horizontal, in-plane freedom of movement whilst the two top fixings have full, in-plane freedom of movement.

When the panel is relatively long (length $\geq 4 \times$ height), it may be advantageous to introduce central, top and bottom fixings, with or without a central support as indicated in Figure 4.7(b). In this case, the bottom central fixing is fully fixed in-plane whilst the corresponding top fixing has no in-plane restraints at all. This arrangement drastically reduces the bending stresses and deflections of the panel.

Both of the panel shapes shown in Figures 4.8 & 4.9 necessitate the introduction of additional fixings having full, in-plane movements as indicated.

The main requirements of any fixing system for a box ribbed GRC panel are:

- (a) All fixings provide lateral restraint whilst allowing a degree of rotation
- (b) One bottom fixing is fixed against in-plane translations, but still allows a degree of rotation at the support where it is located
- (c) All other fixings at support positions, at the bottom of the panel, allow horizontal, in-plane freedoms of movement, together with a degree of rotational freedom
- (d) All other fixings allow full in-plane freedom of movement together with a degree of rotational freedom.

Normally, rectangular, box ribbed panels have four fixings and two supports. There may be, however, good reason to introduce more fixings and supports as the situation demands. These additions must not hinder the free movements of the panel, that is, the panels must not be over-fixed as described in Section 2.

In designing fixing systems, due consideration should be given to all of the following factors:

- a. **Strength and Robustness of the panels**
This addresses the problems of lifting effects, loadings whilst in service, restraints created by the fixings and eccentricities, like the one shown in Figure 4.6(b).
- b. **Buildability**
Adequate tolerances must be provided to facilitate fixing and eventual removal of the panels with safety. The possibility of replacement whilst in service should also be considered.
- c. **Movements of the Panels and Support Structure**
This is a difficult issue to address, particularly when trying to predict how these movements interact. This Guide identifies a number of fixing methods that are intended to overcome these difficulties.
- d. **Health & Safety Issues**
Apart from the obvious ones of handling and transportation, issues about the possible effects of elevated temperatures, fire, earthquakes and blasts should be carefully considered.
- e. **Maintenance**
The design should aim to minimise any necessary maintenance. This maintenance should be formerly scheduled and based on as-built details.
- f. **Dynamic Loading**
The effects of seismic events and blast should be fully investigated in an effort to prevent injury and death.
- g. **Role of Testing**
Even with the power of finite element analysis, the safe load carrying capacity of some fixings is difficult to predict without the help of relevant and reliable test data. The testing of fixings is useful both as a design aid and for compliance monitoring.

4.3.2 Allowing for Movements

Shrinkage, moisture and thermal movements of GRC cladding panels are time dependent and subject to wide variations due to the complexity of the variables involved. In order to avoid distress and possible damage to the GRC, fixing systems should allow these movements to take place unhindered. Additional tolerances may also be required in the fixings to allow for anticipated movement of the supporting structure.

4.3.3 Shrinkage and Moisture Movement of GRC

All cement based materials are susceptible to dimensional changes as they are wetted and dried. After manufacture and cure, shrinkage from the original state occurs as drying takes place. Re-wetting results in expansion but not to the extent of restoring the original size: there is therefore an initial irreversible shrinkage, which will be followed in subsequent service conditions by a reversible dimensional movement dependent on the moisture content of the cement. For GRC the irreversible shrinkage is one quarter to one third of the total possible shrinkage. Typical figures for a 1:1 sand:cement ratio GRC mix are 0.03%

irreversible shrinkage and a total ultimate shrinkage of about 0.12%. The shrinkage and moisture movement behaviour are represented diagrammatically in Figure 4.10.

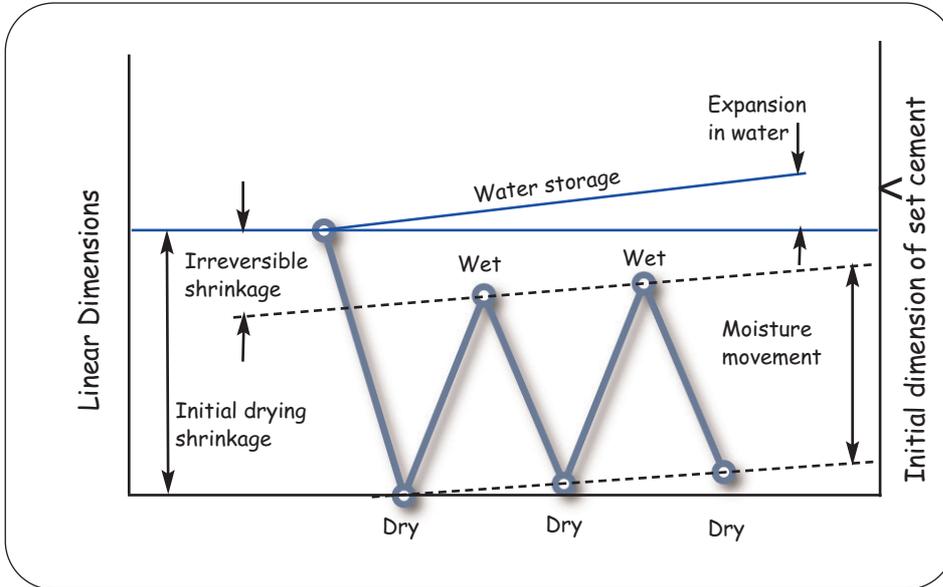


Figure 4.10 - Shrinkage and moisture movements of GRC

It should be noted that the amplitude of reversible movement quoted above is between fully-dried and fully-soaked conditions laboratory conditions. In practice, these extremes may not be experienced in normal weathering conditions, although there will be some cyclic movement about a mean level which is effectively shrunk relative to initial manufactured dimensions.

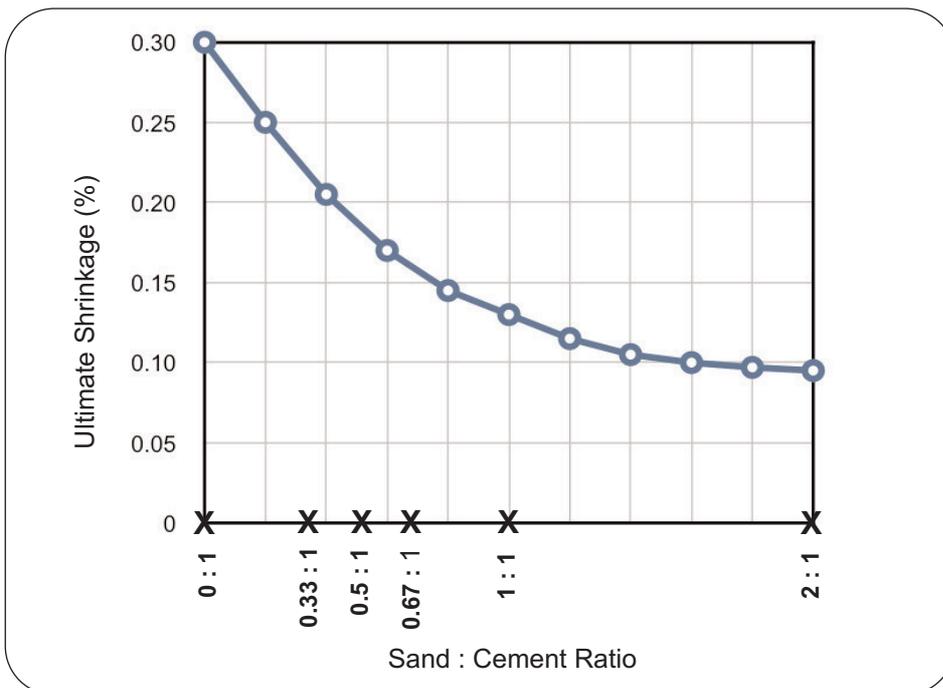


Figure 4.11 - Variation of drying shrinkage with sand : cement ratio

As a general guide, the irreversible shrinkage amounts to one quarter to one third of the ultimate drying shrinkage and is largely dependent on the water/cement ratio. Moisture movements tend to decrease with age and are mainly governed by the cement content. The typical variation of ultimate drying shrinkage (%) with the sand/cement ratio is indicated in Fig 4.11.

Current practice is to use a sand : cement ratio of 1:1. This can result in a free shrinkage or moisture movement of 0.12% or 1.2mm per metre length. It is imperative that these movements are not inhibited in any way. If a length of GRC cladding were restrained against free shrinkage, the induced **tensile** stress could be as high as:

$((15 \times 1.2 / 1000) \times 1000) \text{ N/mm}^2$, ie 18 N/mm² which is excessive. This calculation assumes an elastic modulus of 15 kN/mm².

4.3.4 Thermal Movements of GRC

The magnitude of thermal movements in GRC can be of a similar order to shrinkage and moisture movements. If these movements are restrained, significant stresses can be induced into the GRC.

The coefficient of expansion (α) of GRC is within the range of 10 to 18 $\times 10^{-6} / ^\circ\text{C}$. Thermal dimensional changes in the GRC can be calculated from the well-known formula:

$$\Delta L = \alpha \cdot \Delta T \cdot L$$

where ΔL = change in length

α = coefficient of linear expansion

ΔT = change in temperature

and L = length over which ΔL is being measured.

Example

Assuming a rise in temperature (ΔT) of 30 $^\circ\text{C}$ and a value of coefficient of linear expansion (α) of 18 $\times 10^{-6}/^\circ\text{C}$ a 2.500 metre long panel will expand by

$$(18 \times 10^{-6} \times 30 \times 2.5 \times 1000) \text{ mm} = 1.35 \text{ mm}$$

NOTE
Panels of single skin construction are now generally used in preference to sandwich panels because the latter are prone to bowing and concentrations of differential temperature / shrinkage stresses.

GRC cladding panels of single skin construction are usually stiffened with ribs formed around expanded foam. Sandwich panels are double skin construction with a core of expanded foam. In both cases, the GRC on opposite sides of the core material is likely to experience different conditions of temperature, humidity and moisture content.

These differing conditions have a tendency to produce bowing of the panels. This bowing only occurs to a limited extent in ribbed GRC but can be very pronounced in sandwich construction. Clearly, some account of this bowing must be made if it is likely to affect the performance of the fixings. Care must be taken to place fixings in positions which do not restrict this bowing, otherwise significant secondary stresses can be induced into the GRC panels.

If a panel experiencing a fall in temperature of 30 deg C were to be fully restrained, the induced **tensile** stress is equal to:

$$E \cdot \Delta L / L \text{ N/mm}^2$$

ie $(15 \times 1.35 / 2500) = \underline{8.1 \text{ N/mm}^2}$ still excessive.

4.3.5 Movements of Supporting Structure

The movements that are common to both concrete and steel structures are:

- elastic deformation under load
- sway of the building under load
- thermal movements
- deflections of beams under load
- possible differential settlements of the foundations.

In addition, concrete structures are subject to shrinkage/moisture movements and creep of the concrete under sustained loading.

It is generally very difficult to quantify these movements with any degree of accuracy so a conservative approach should always be used. Constructions which alleviate the effects of any of these movements should be used whenever possible. One method of overcoming problems associated with the deflections of the main beams and floor slabs of the building is to provide a separate, adjustable steel framework, wholly supported at ground level, for supporting the GRC cladding as shown in Fig 4.12 (b). This construction allows the main beams to deflect independently whilst still giving lateral restraint to the secondary support steelwork which is supporting the GRC cladding. The construction shown in Fig 4.12 (a) **must not** be used as the tops and bottoms of the GRC panels are fixed to different lengths of support steelwork which can move relative to one another.

NOTE
Secondary steelwork support systems for GRC cladding panels should be fully adjustable in both the horizontal directions to offset possible out-of-tolerance(s) of the main steelwork.

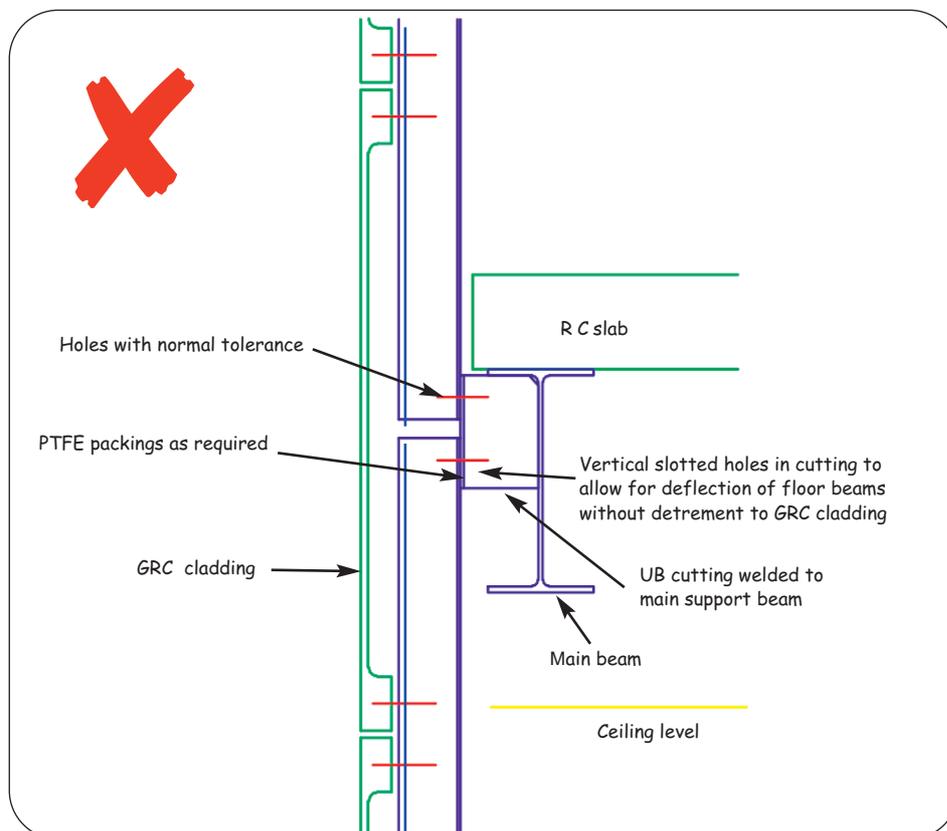


Figure 4.12 (a) - Incorrect method of fixing GRC cladding to secondary steelwork

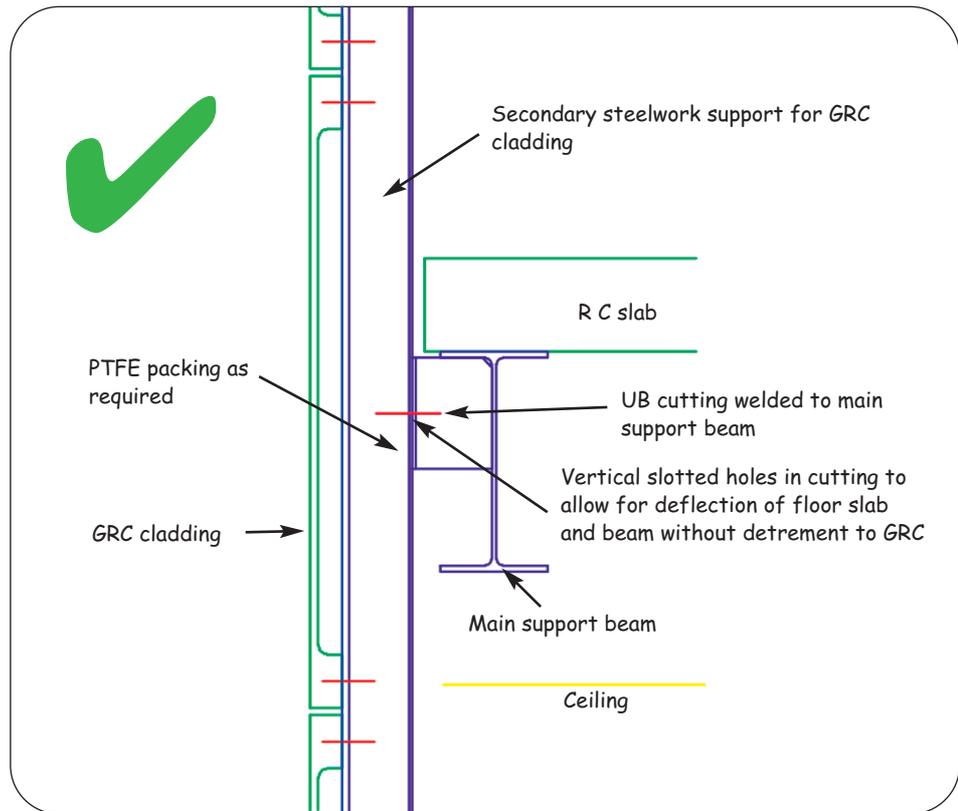


Figure 4.12(b) - Correct method of fixing GRC cladding to secondary steelwork

4.4 Wind Loading Effects

The wind loading on GRC cladding and its fixings should always be determined from the guidance given in local or applicable codes of practice relevant to the area. In UK, designers work to BS 6399 - 2, BS 8297:2000 and other associated documents. The design wind load in UK can vary from 0.5 to 2.5 kN/m² depending on its location, exposure and height above sea level. Wind contours produced by the Building Research Establishment indicate that the worst basic hourly mean wind speeds, in metre/sec, occur in the very north of Scotland, down the east coast of England, on the west coast of Scotland close to Glasgow and across the north and west coasts of Ireland. These hourly mean wind speeds are used to calculate design wind loads. Higher wind loads can occur in narrow gaps between buildings, thereby exerting high local pressures and/or suctions on the panels, depending on the direction of the winds.

Rainscreen cladding and over-cladding may suffer from the combined effects of high suction forces behind them in the cavities and positive pressures acting on their windward faces.

Particular attention should be given to GRC clad canopies, balconies and appendages, such as chimney stacks, ventilators, smoke vents etc and other architectural features. The shape of the cladding is very important, eg the wind forces acting on a GRC clad minarette for a mosque is substantially greater for one having a hexagonal section than it is for one that is circular.

As another example, consider a cantilever canopy clad with GRC panels, high on a building (Figure 4.13). It can suffer upward acting forces as indicated in Figure 4.14(a). Conversely, the same construction positioned low on a building can experience downward acting forces as shown in Figure 4.14(b).

On very large, prestigious (and unusual) schemes involving the use of GRC, or any other form of cladding, there is presently no more accurate way to obtain design wind pressure coefficients than those derived from wind tunnel tests carried out on a representative model of the proposed development.



Figure 4.13 - Example of a cantilever canopy.

See Project 9 in Part 2 of this Fixing Guide for details of this stud frame construction.

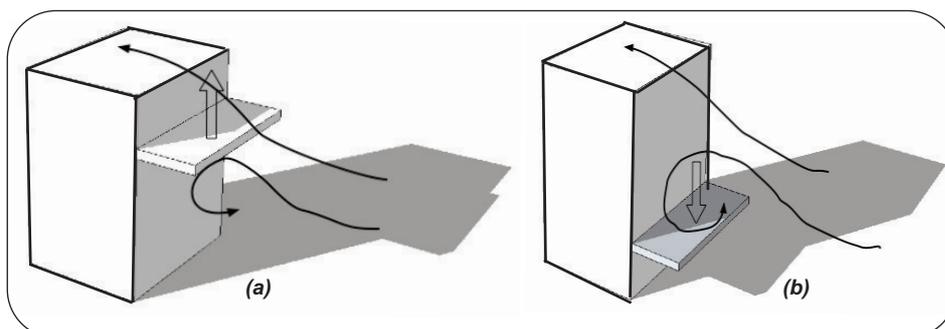


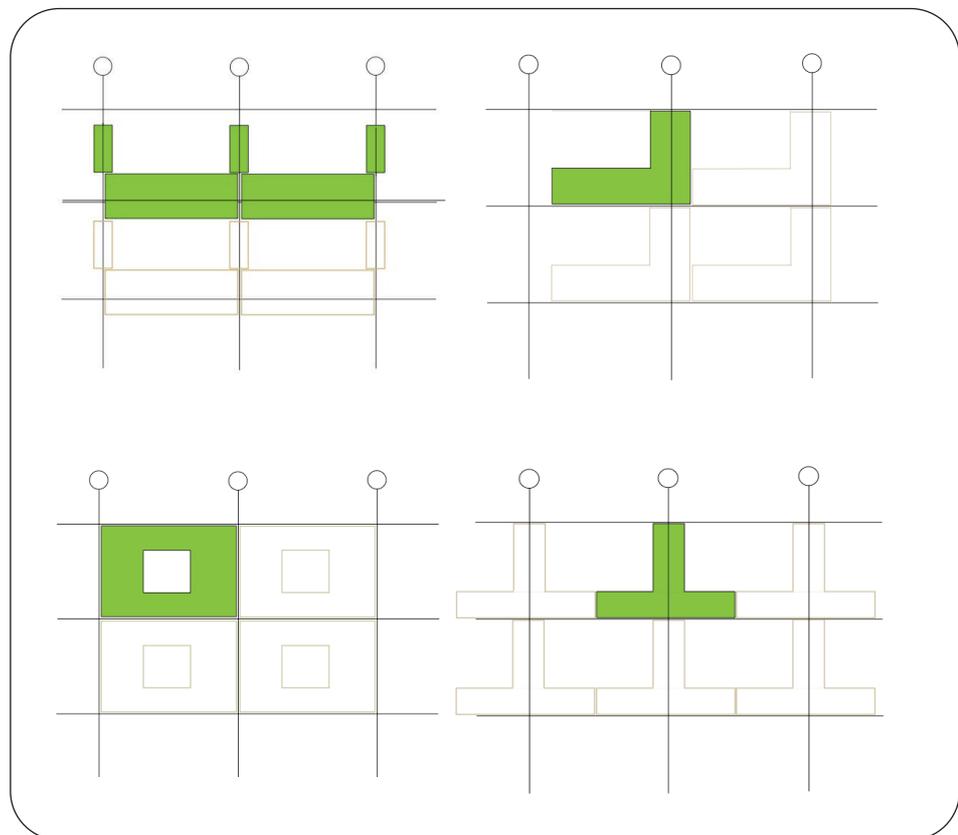
Figure 4.14 - Resultant wind loads on canopies

4.5 Seismic Effects

In non-residential buildings, earthquake damage is mainly sustained by non-structural elements comprising the building envelope. Potential damage to GRC cladding panels depends on the interaction between the cladding and building structure during a seismic event. This damage results from closing of gaps, tolerances and joints between adjacent panels and between panels and the structure. Buildings with superstructures that are simple, symmetrical and regular, in both plan and elevation, are less prone to developing excessive torsional forces that can badly damage GRC cladding panels. In seismic zones, building superstructures should have regular and shorter spans than similar ones in non-seismic areas. They should also avoid the use of long cantilevers.

The lightweight advantage of GRC cladding panels results in significant reductions in seismic forces acting on the panels. When designing GRC cladding panels in seismic regions, due consideration should be given to the requirements for movement, ductility and strength. GRC cladding is generally designed to move with the structural frame support and must accommodate lateral drifts. Consequently, horizontal joints should be continuous, as indicated in Figures 4.15 (a) to (d). As a general rule, GRC cladding systems designed to resist earthquakes should also be able to resist blast (terrorism) with less damage.

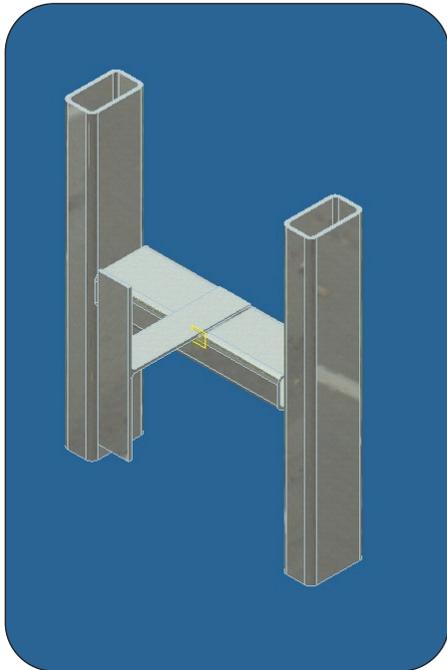
The increased use of glass reinforced cladding panels has enabled more sculptured forms of lighter, cementitious panels to be produced, thereby presenting less weight to the ravages of seismic activities. This makes GRC cladding panels particularly suitable in seismic regions.



Figures 4.15 (a) - (d) - Various arrangements of GRC cladding panels

Box rib cladding panels in seismic regions should be effectively stabilised by fixing them to the support structure at their centre of gravity to avoid damage due to movements induced by the earthquake. Clearly, this seismic fixing is in addition to those illustrated in Figures 4.7, 4.8 & 4.9. The form of this fixing can be as illustrated in Figure 4.16.

There is no doubt that GRC stud frame construction is much more suitable than

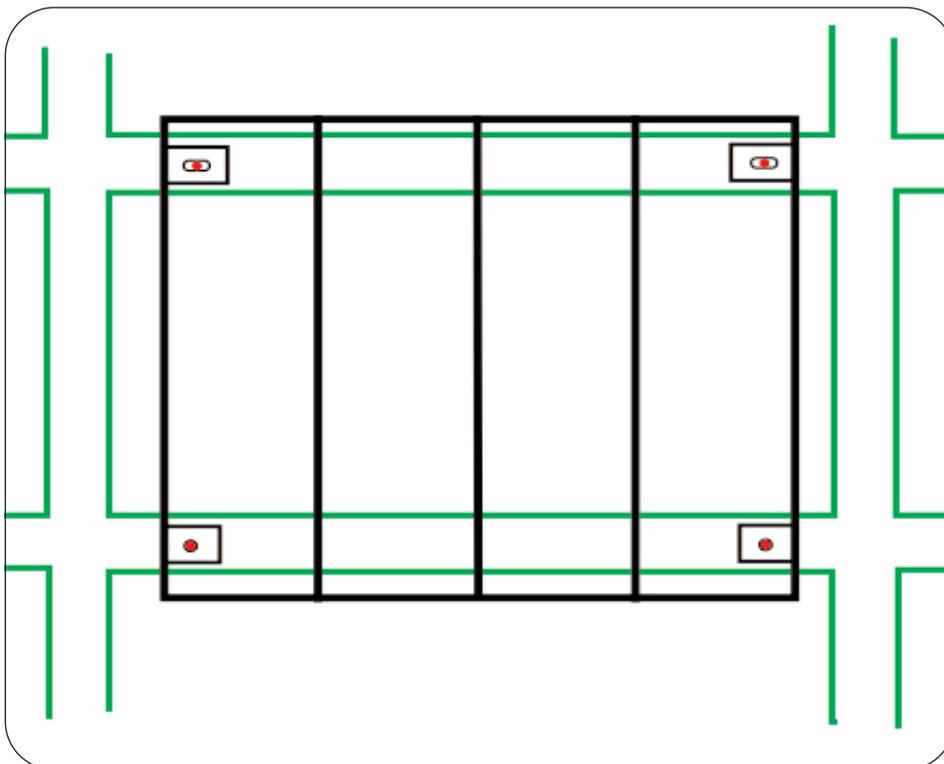


box rib or sandwich construction for resisting the damaging effects of earthquakes.

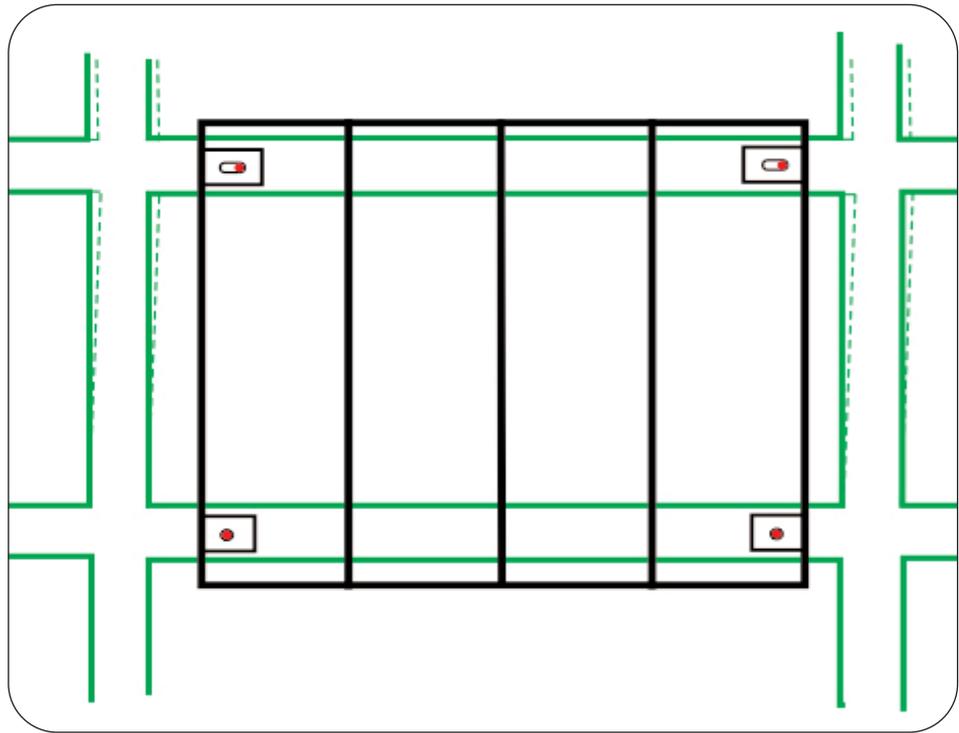
In stud frame construction, the facing can be secured at its centre of gravity to the frame, again using a fixing like that illustrated in Figure 4.16. In addition, the stud frame can be secured to the support structure using one of two fixing details that allow some movements of the frame during the earthquake.

The first fixing detail, often referred to as the 'sway' type is shown in Figures 4.17 and 4.18. The bottom fixings support the self-weight of the panel whilst the top two fixings can either be flexible rods that bend during the earthquake or bolts that slide horizontally in slotted holes. In the latter case, the use of lock nuts are recommended.

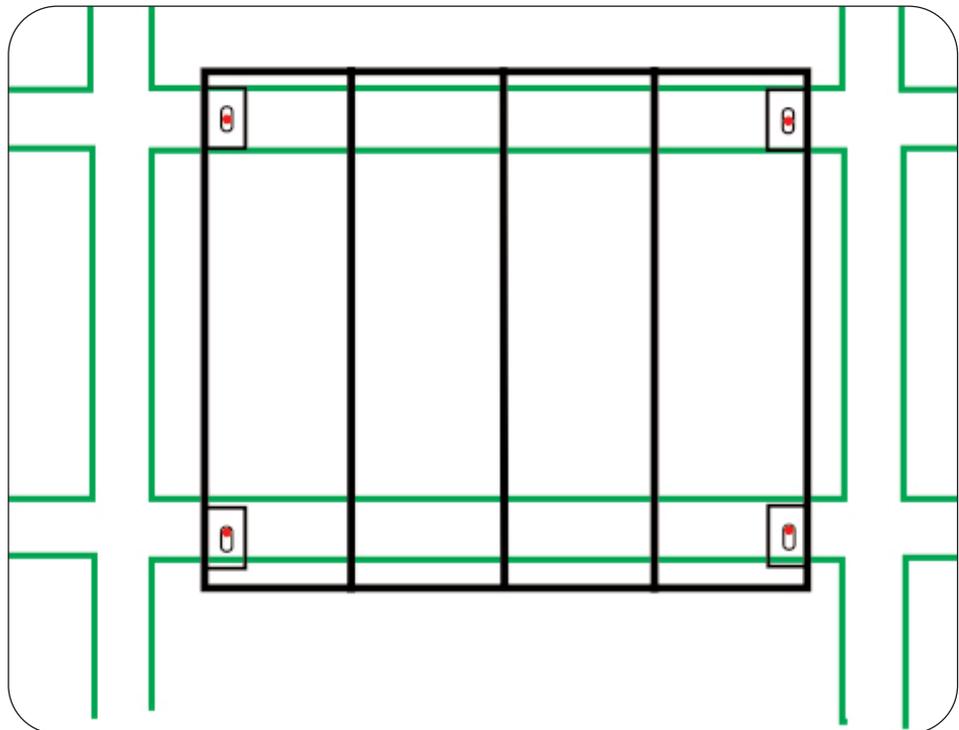
Figures 4.16 - Seismic fixing positioned at centre of gravity of GRC facing



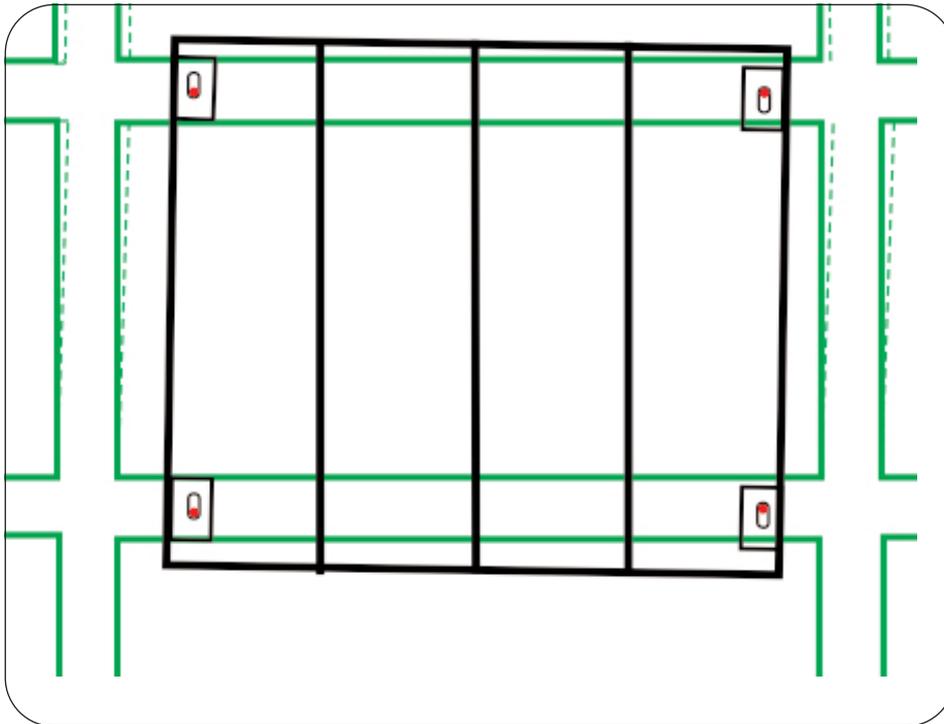
Figures 4.17 - 'Sway' seismic fixing before sway



Figures 4.18 - 'Sway' seismic fixing after sway



Figures 4.19 - 'Rocking' seismic fixing before sway



Figures 4.20 - 'Rocking' seismic fixing after sway

The second fixing detail accommodates drift by a 'rocking' motion. Figures 4.19 and 4.20 illustrate this type of fixing. The choice of which one to use depends on the type of support structure. The 'sway' fixing is better suited to rigid support structures, eg concrete walls, whilst the 'rocking' fixing is the one to use where flexible framed structures are used for the support system

4.6 Blast Effects

Blast loadings on GRC cladding panels can be generated from either the inside or outside of the building. A typical example of an inside blast is that of a gas explosion. Outside the building, the cladding panels may be vulnerable to the ravages of car bombs. In design, inside blasts can be idealised as a uniformly distributed load (UDL) acting on each exposed panel, eg a gas explosion load of 34 kN/m^2 .

The lower four storeys in multi-storey buildings are the most vulnerable to car bomb attacks. Calculating the effects of car bombs is far more complex due to their non-linear characteristics. It is better to minimise their damage in the first place by creating a stand-off zone around vulnerable parts of the building. This is usually achieved by erecting bollards and/or barriers or controlling pedestrian entry points.

GRC panels in sensitive zones should be over-designed by 1.75 to 2 times to mitigate the effects of the bomb blast. The panels should also be designed for a ductile response. This suggests that premix and/or sprayed premix panels would not be suitable due to their "brittle" type failure characteristics, namely, a low strain to failure. It is, therefore, advisable to use sprayed GRC panels (Grade 18) in situations where blast loading may occur. After the initial positive blast loading the panels are subjected to a reflected (negative) pressure ie a suction. In the absence of any reliable data, it is conservative to assume that the magnitude of this negative pressure is equal to that of the positive pressure.

Box rib and sandwich type GRC panels cannot be expected to contribute to the strength of a building during a blast. However, panels in a stud frame construction may well do so, depending on the nature of the fixings. Some form of connection

between stud frames can maintain alignments and facilitate in the event of a blast (Figure 4.21).

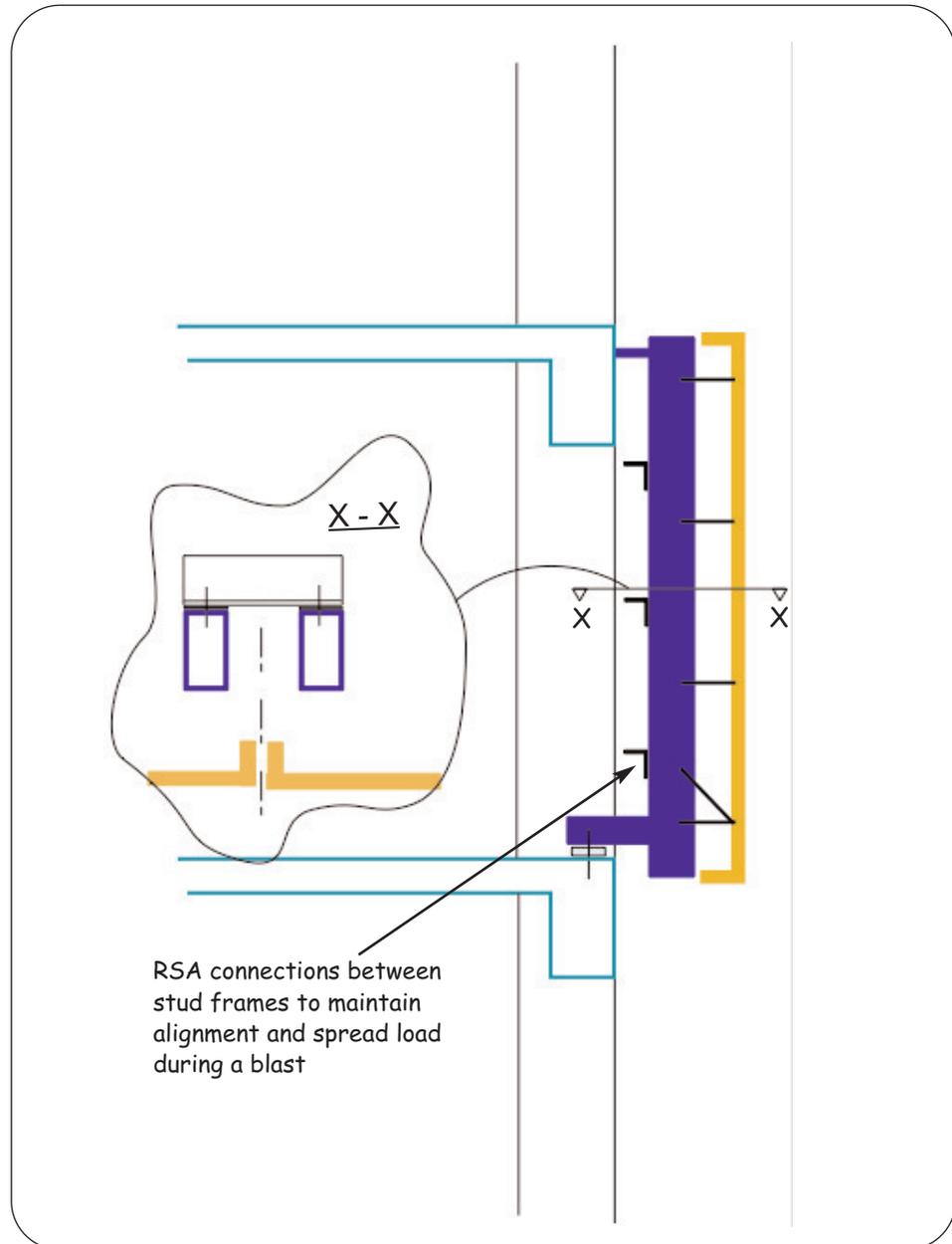


Figure 4.21 - Fixing of GRC cladding to floor diaphragms instead of columns

Deep surface features should be avoided in panels that might suffer a blast. These features create complex reflections and can lead to a significant amount of damage.

The sizes of panels in blast zones should be a storey height so that they can be secured to the floor diaphragms. This avoids overstressing the columns which give support to the main structure.

These panels should also have flexibility to bend or break whilst remaining essentially intact. The use of fine, polymer grid reinforcement can avoid the panel from breaking up into small pieces. These grids respond rapidly to sudden loadings. Clearly, the geometry and size of the grid elements must be such that they do not cause delamination. The fixings between the panels and the main structure should be designed to withstand loads of at least 1.25 times those used for the design of the panels.

Moreover, these fixings should be as direct as possible using the minimum number of connecting pieces. In a blast, fixings may be stressed up to near their ultimate capacity. Consequently, single connection failures should be considered in design. In so doing, all possible load paths must be identified and taken into account. Fixings subjected to blast loads should also have sufficient rotational capacity as well as strength. If fixings become unstable at large displacements, failure can occur.

The behaviour of GRC panels in blasts can be investigated using digital prototype testing based on linear and non-linear finite element analyses. Correlation with the results of physical testing will obviously yield the best understanding of this type of complex loading.

4.7 Joints between GRC Cladding Panels

4.7.1 Layout of Joints

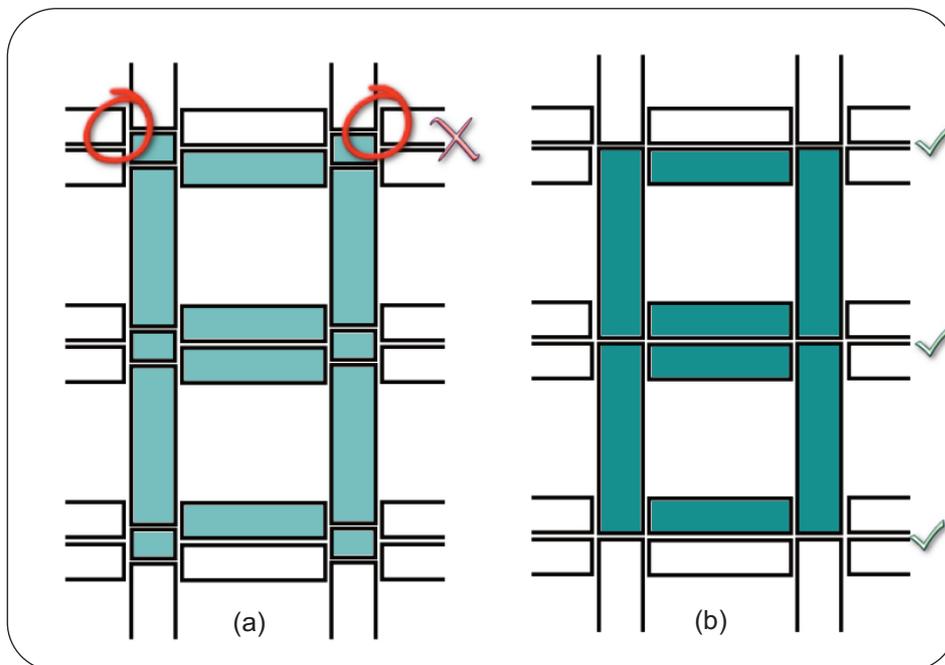


Figure 4.22 - Positions of horizontal joints

The basic rules for layout of joints in GRC cladding are as follows:

- a. Small to medium sized windows should be accommodated within a single panel to avoid lack of fit and joint sealing problems.
- b. Horizontal joints should be continuous (Figure 4.22(b)). This avoids problems with lateral drift in multi-storey structures. The layout shown in Figure 4.22(a) could obviously result in stress in some of the column panels.
- c. Integral returns on panels should be kept as small as possible (< 300mm), as these are usually vertical when spray methods are being used. This deters sagging of the material during spraying.

The positioning of vertical joints also requires careful consideration. If these are not in line, e.g. the vertical joint between two panels is positioned over the centre of the panel below, there is a potential risk of the panel below being stained whilst in service.

4.7.2 Sealing of Joints

It is recommended practice to apply a primer before applying an elastomeric sealant. This ensures a good bond between the sealant and the panel. This also reduces the possibility of staining the face of the panel. A backing strip provides the dual purposes of providing a stop for the sealant but also acts as a bond breaker ensuring that the only bonded surfaces of the sealant are the inside faces of the joint (Figure 4.23).

Whilst the depth of a silicone sealant is generally about 10mm, irrespective of the width of the joint, up to a width of 20mm, it increases to 15mm for joints equal and greater than 30mm. In the case of polysulphide sealants, their width:depth ratio is generally about 2:1. It is good practice to ensure that the outer edge of sealant is stopped approximately 2 - 3mm from the front face of the joint to avoid staining. These figures are only given for guidance. In practice, the joint sealant must be

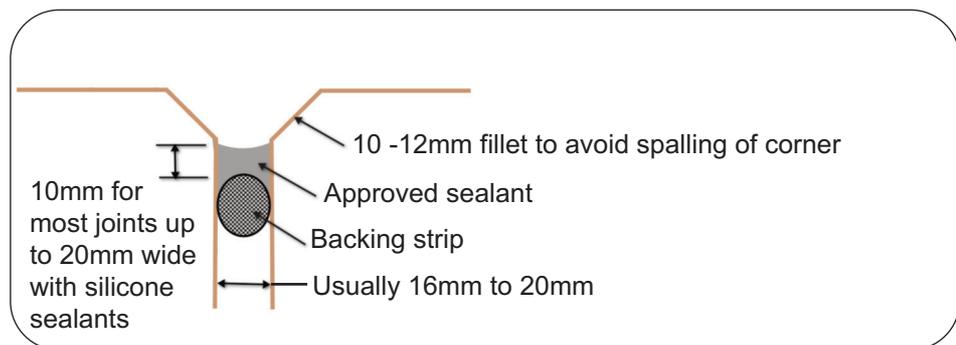


Figure 4.23 - Fixing of GRC cladding to floor diaphragms instead of columns

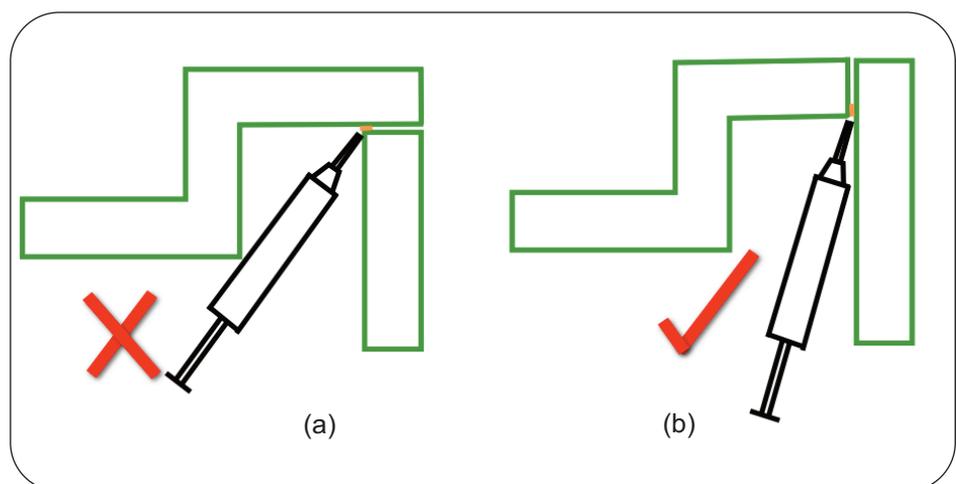


Figure 4.24 - Overcoming poor access by detailing

properly applied in accordance with the Manufacturers criteria and instructions. The backing strip is usually a closed cell, medium density, polythylene foam strip or rod. It is normally 30% greater than than the width of the gap into which it is to be compressed.

The joint arrangement shown in Figure 4.24(a) is typical of a situation where the Architect is trying to hide the joint. It is obvious that it will be difficult to seal the joint properly because of the poor access. Figure 4.24(b) shows a much better arrangement since it is far easier to seal the joint.

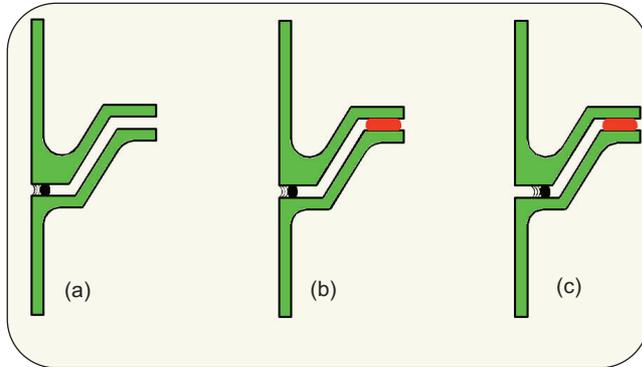


Figure 4.25 - Joggle joint

The horizontal joggle joint shown in Figure 4.25 is not too popular because of the following perceived drawbacks:

- a. Difficult and costly to make
- b. Can conflict with lifting sockets in the top of the panel
- c. Makes it difficult to carry out future inspections
- d. Can make alignment of vertical and horizontal seals difficult

Horizontal joggle joints can be sealed using the single seal arrangement shown in Figure 4.25(a). Alternatively, a double seal can be achieved by positioning and sticking a compression type seal to the lower panel before the panel above is positioned over it, then finally sealing the joint conventionally close to the outside faces of the panels as shown in Figure 4.25(b).

Some architects and engineers prefer not to see the sealant, firstly to view the joints in shadow and secondly to avoid the unsightly appearance of sealants that attract atmospheric pollution, thereby becoming discoloured.

Clearly, the joint sealing arrangements discussed above also apply to straight horizontal joints. Another way of double sealing the joints would be to use two of the sealant type indicated in Figure 4.25(a), with a gap in between them.

Another practical consideration is that of the effects of air temperature at the time of installing the sealant. When the sealant is applied in summer, at a higher than ideal temperature, the sealant will suffer increasing strains in tension during the colder winter months. These strains can be reduced by using sealants such as silicones or two-part polysulphides that do not reach a set condition until a few hours after application during cooler night temperatures. It is more difficult to estimate the benefits of using one-part polysulphide or two-part polyurethane sealants because of their much slower curing properties. Another way of reducing these tensile strain effects is to specify a wider joint than that determined from the joint design. Shrinkage of the panels that occurs before installation of the sealant could increase the joint width and is, therefore, an advantage.

Lap joints can accommodate larger movements and are less obtrusive. The sealant acts in shear rather than in tension/compression. However, they are more difficult to form and maintain and so they are not generally used.

4.7.3 Widths of Joints

The specified widths of joints and joint type of sealant for GRC cladding panels should account for the combined effects of shrinkage, temperature/moisture changes, panel sizes, support conditions and tolerances (manufacturing, erection and interfacing on site). The widths of joints are not purely aesthetic, they must address all of the above requirements and be sealed with a sealer that can accommodate all of the above movements and remain serviceable throughout its design life. Temperature variations should be estimated with due consideration to the location of the panels relative to the sun; panels facing south will experience higher temperatures than those facing in other directions.

Section 4.3 of this publication explains how shrinkage and temperature/moisture effect GRC panels whilst Section 6 gives guidance about the estimation of various tolerances.

Panel sizes and support conditions can have a significant effect on the variation of joint widths and consequently on the design and choice of a suitable sealant. Reference should be made to the sealant manufacturer's literature to ensure the correct product has been specified.

Support conditions are usually more critical for panels supported on steel beam constructions than those supported on the alternative reinforced concrete ones, simply because deflections of the former are generally greater. Ideally, if GRC panels are to be supported on steelwork, it should be separate from the main structure but secured to it to for lateral restraint . This steelwork has only then to support its own self weight and that of the cladding panels.

Difficulties can arise when panels are supported on the beams of a composite structure. These beams support all associated dead loading and imposed loading, as well as the self weight of the panels. Clearly, the beam deflections will be larger in this case, so the cladding panels will rotate more in the vertical direction as shown in Figure 4.26. This results in a reduction of the joint widths and greater compression of the joint sealants towards the tops of the panels. The actual reductions of the joint widths are dependent on the sizes of the panels, both in height and width, together with their positions along the beam.

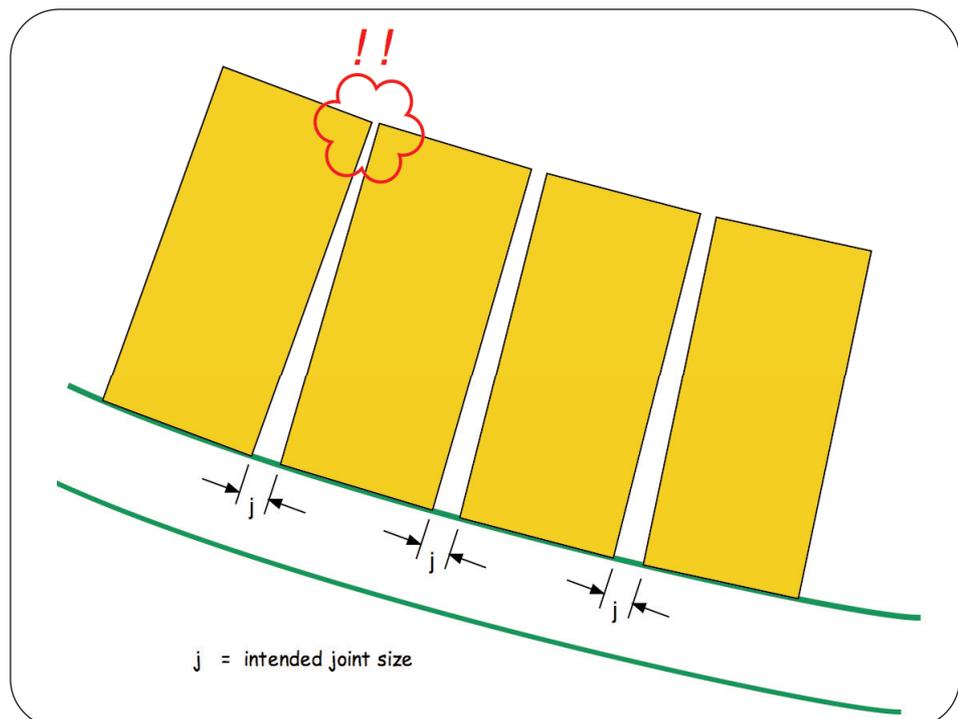


Figure 4. 26 - Elevation showing variation of joint thicknesses due to deflection of beam

A practical way to determine the variations in joint widths due to the deflections of the supporting beam is to draw the arrangement of panels on the deflected shape of the beam using one of the modern CAD packages, like AutoCAD. If the GRC panels are supported on a single beam, their self weight loading can be idealised as a uniformly varying load (UDL) acting over the full span. The deflections at various points along the length of the beam can be accurately calculated using a 'plane frame' or 'beam' software package. Alternatively, for this simple UDL loading, the deflected shape of the beam can be found from the expression

$$y = k_1 \cdot (w L^4 / EI \times 10^3) \text{ mm}$$

where

y = deflection at distance x (mm) from left hand support

w = self weight UDL of cladding panels + self weight of beam (kN/m)

L = span (mm)

E = Young's Modulus (kN/mm²)

I = second moment of area of beam (mm⁴)

Values of the dimensionless factor k_1 for corresponding values of (x / L) are given in Table 4.1 below.

Table 4.1

x/L	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
$k_1 \times 10^3$	0	4.09	7.73	10.59	12.40	13.02	12.40	10.59	7.73	4.09	0

Hence, the deflection at the centre of the beam is

$$(13.02 / 10^3) \times (w L^4 / (EI \times 10^3)) = 0.01302 (w L^4 / (EI \times 10^3)) \text{ mm}$$

NOTE
5/384 = 0.01302

Values of y can be plotted against corresponding values of (x / L) from 0 to L. The deflection points can then be joined to form a polyline. This can be 'fitted' to the curved deflected shape using the PEDIT command in AutoCAD.

This shape is reasonably accurate and can now be used as the baseline onto which to plot the GRC panels. Any problems with joint widths will soon become apparent.

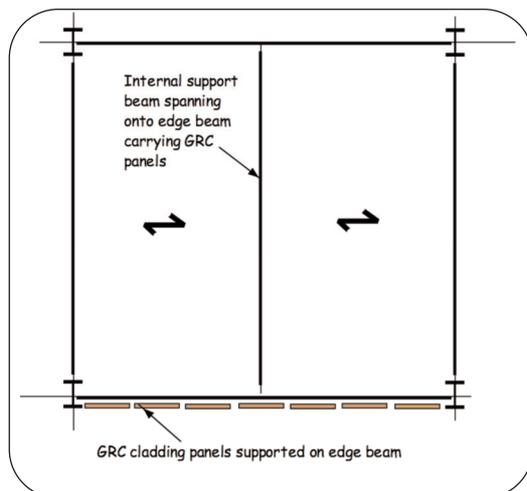


Figure 4.27 - Rear view of hybrid, stud frame construction

When the edge beam is required to support the GRC panels and a central point load reaction from an internal support beam (Figure 4.27), the additional deflections due to the central point load of P (kN) are determined from the expression

$$y = k_2 \cdot (PL^3/EI) \text{ mm}$$

where

y = deflection at distance x (mm) from left hand support

P = central point load (kN)

L = span (mm)

E = Young's Modulus (kN/mm²)

I = second moment of area of beam (mm⁴)

Values of the dimensionless factor k_2 for corresponding values of (x / L) are given in Table 4.2 below.

Table 4.2

x/L	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
$k_2 \times 10^3$	0	6.17	11.83	16.50	19.67	20.83	19.67	16.50	11.83	6.17	0

Hence, the additional deflection (y) due to the central point load P is

$$(20.83/10^3) \times (PL^3 / EI) = 0.02083 (PL^3 / EI) \text{ mm}$$

NOTE
1/48 = 0.02083

The combined deflection profile is now used as the baseline onto which the arrangement of panels is plotted. Again, any problems with joint widths will soon become apparent.

When the pattern of internal beam(s) is unsymmetrical, it becomes necessary to use a suitable software package to determine the deflected shape of the edge beam.

4.8 Rainscreen Constructions

4.8.1 Introduction

The cladding of a modern structure is a critical and specialist subsystem of the total building delivery team. In recent years popularity in “Rainscreen” envelope methodology has steadily increased.

A rainscreen cladding comprises external decorative panels (that shed much of the rain and which can be made of a wide range of materials), an airgap, a vapour barrier and a supporting backing wall. The panels are normally supported off the backing wall by a grid of metal supports, typically the latter belong to a particular (proprietary) cladding system.

Properly detailed and built, the rainscreen system is an effective envelope solution to external moisture penetration. This chapter of the fixing guide reviews the various forces that move rain into buildings and suggests how they can be counteracted. Aspects of building geometry and aerodynamics are discussed as well as the components of wall assemblies. The rainscreen principle and the process of pressure equalisation are explained later on (Figure 4.28).

4.8.2 Rainwater Penetration

It is a well established fact that, water is one of the most significant factors in the premature deterioration of buildings. It can cause corrosion of metals, rotting and mold in organic substances, reduction in effectiveness of insulation, efflorescence, stresses, movement and breakage due to freeze/thaw cycling.

Three conditions are required to move water through the building envelope:

- A source of water
- An opening or path for the water to follow
- A force to drive the water through the opening

If one of these conditions is absent, moisture penetration cannot occur.

Joints between materials and around windows and doors, vents, cracks, and porous surfaces are all potential entry points for water. Approaches to controlling rain penetration that rely on sealing openings without also dealing with the forces driving rain into buildings are often not fully effective. The forces that drive rain into buildings can be summarised as **kinetic, gravity, capillary action, surface tension, and pressure gradients**. The most significant are gravity, capillary action and wind pressure differences, causing pressure gradients.

Kinetic force refers to the momentum of wind-driven raindrops. This force will carry raindrops directly through openings of sufficient size. Wind driven rain can have a significant horizontal velocity, and near the top of a building this force may even have an upward component.

Gravity can be used to our advantage in controlling rain penetration of vertical building elements. Flashings can intercept water coming from above and direct it to the outside and away from building surfaces.

Surface tension allows cohesion of water droplets, even against gravity and across small openings.

Capillary action these forces allow water to cling to and flow along horizontal surfaces, such as soffits, and to move against gravity through cracks and pores in building materials.

Pressure gradients air pressure differences across the building envelope can create suction, drawing water through available leakage paths. Pressure differences across the building envelope can result from **wind, mechanical systems and the stack effect** [see Section 4.9]. The latter two can be considered static pressures, as they are relatively constant and act on all sides of the building in the same way at any given height (although they can vary over the height of the building). Of primary concern in controlling water infiltration is the pressure difference due to wind, as it is generally much higher and more variable. Even a steady wind does not create uniform pressures across a building, as airflow patterns around building edges create varying wind velocities and forces. Air pressures due to wind will be positive on the windward faces of a building, and negative (for example, suction or uplift) on the leeward side and, often, the roof. Cyclic pressures due to gusting winds, meanwhile, can create significant variations over very short time periods. **Compensating for these variations in wind pressure is one of the key functions a properly designed rainscreen** this is achieved by proper and correct pressure equalisation in the wall cavity .

4.8.3 Approaches to controlling rainwater penetration

Traditional construction techniques have worked in various ways to counteract the forces bringing rainwater into buildings. Mass wall systems, such as solid brick, block, stone and concrete, rely on the wall surface to shed most rain, while the massiveness of the material allows it to absorb and hold remaining surface moisture. The absorbed water later evaporates during a dry period, with solar or indoor heating assisting the process.

Face-sealed systems, in contrast, try to eliminate leakage paths through which water can enter the wall. Water-resistant exterior surfaces are used and joints are sealed. This approach tends to be unreliable in modern, insulated veneer wall systems, especially in harsh climates, where large temperature gradients exist across the through wall structure. The wall surface reacts quickly to changes in outdoor temperature and sun exposure. Thermal movement and cracking can result, with failures typically occurring at the joints, which are subject to additional stresses such as deterioration of sealants due to moisture contact, freezing and thawing, solar radiation, etc. The low permeability of the wall materials to water may exacerbate the problem, as water entering the wall assembly becomes trapped. The complete face-seal approach can work, but ongoing maintenance of the sealed joints is necessary.

A better approach may be to provide water-resistant, sealed surfaces with rain screen joints. The rain screen wall addresses all of the forces we have described that move rain into the wall. The basic configuration, incorporating two layers, or wythes, separated by an air space, has variations that provide different levels of rain protection effectiveness. A distinction should be made between the drained cavity wall, the simple or open rain screen, and the pressure-equalized rain screen wall. What is usually meant by a “rain screen wall” is generally the latter: an exterior cladding, a cavity behind the cladding, drained and vented to the outside; an inner wall plane incorporating an air barrier; and a set of compartment seals limiting the cavity size. The outer “screen” layer of cladding deflects the kinetic force of the rain, while the inner wythe remains protected. The vented cavity uses gravity and flashings to drain water that penetrates the outer wall, away from vulnerable surfaces and joints. The cavity is sufficiently wide that surface tension and capillary action are not able to move water across the cavity.

4.8.4 Summary

It can be summarised that rainscreen systems are an effective way of delivering a weatherproof and durable envelope to structures within the built environment. The most effective results can be achieved with a pressure equalised rainscreen wall system, made up from the components discussed. The outer wythe requires elements that have some of the properties inherent with GRC.

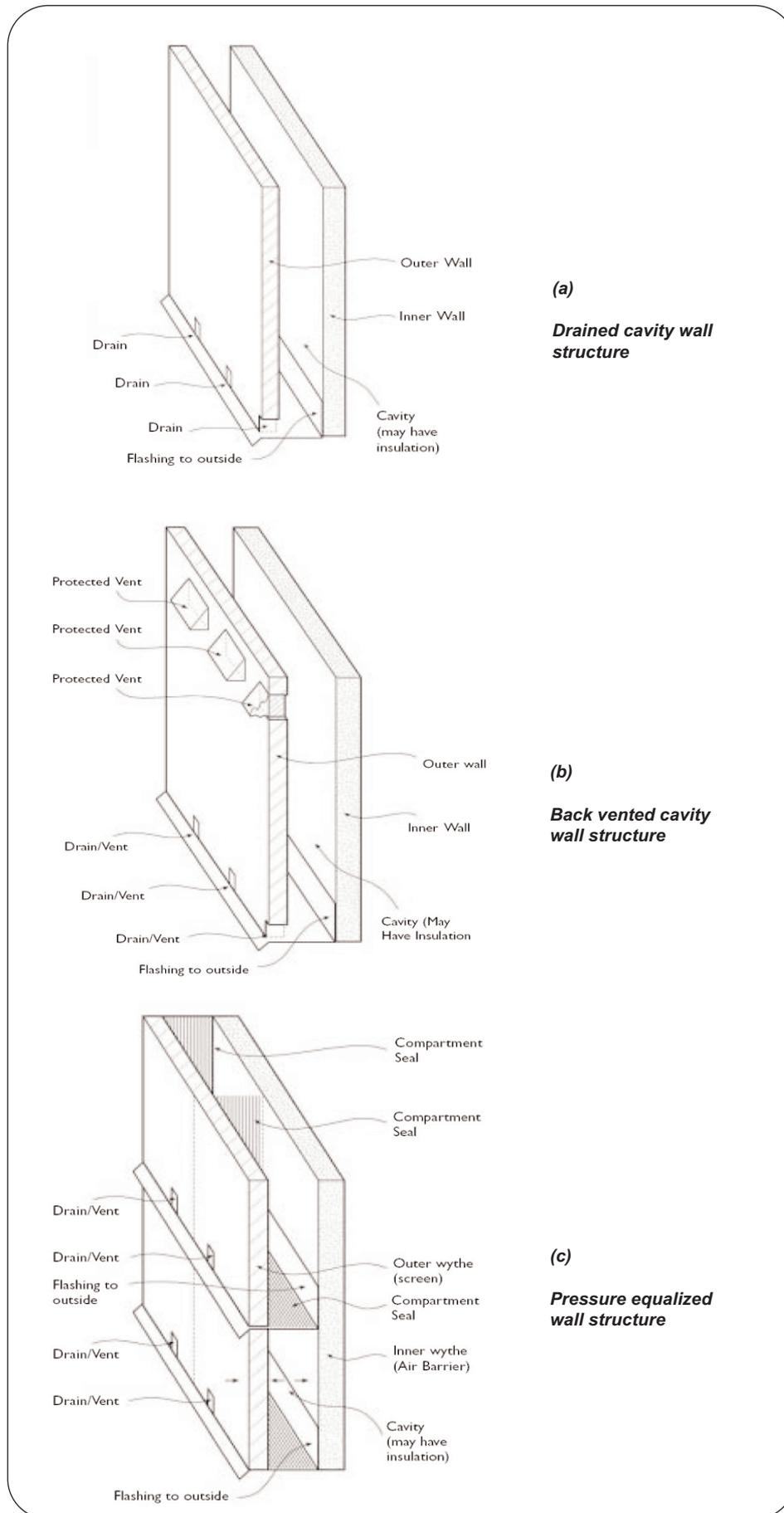


Figure 4. 28 - Rainscreen constructions

4.9 Stack Effect

Differences in air temperature between indoor and outdoor air cause the warm air to rise inside a building. This is called the 'stack effect'. As the warm air rises, it creates a suction at the base and exerts an outward pressure towards the top of the building. The higher the building, the greater the pressure difference across the walls and roof.

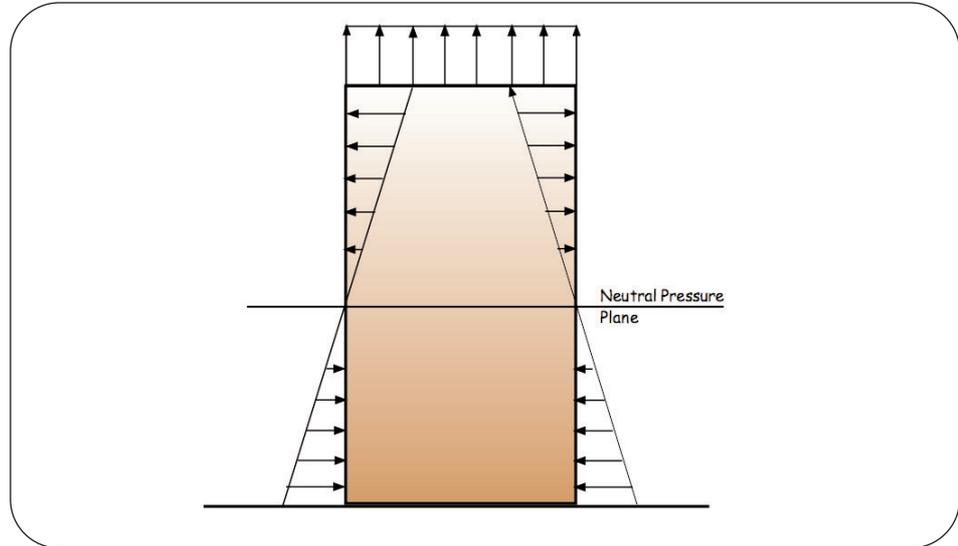


Figure 4. 29 - Variation of pressure due to the 'stack'effect'

Figure 4.29 indicates that the suction is greatest at the base, decreasing upwards until it reaches the so-called neutral pressure plan. Above this level, the pressure acts outwards and increases until it reaches a maximum at roof level. These pressures could be acting directly on the external and internal faces of the building envelope eg GRC cladding. This phenomenon is worst on high-rise buildings in cold climates. The pressures due to the 'stack effect' are height and temperature dependent. Figure 4.30 shows the likely variation of the outward acting pressures at various distances above the neutral pressure plane with different temperature differences, inside to outside. Pressures due to the 'stack effect' should be added algebraically to those due to normal wind pressures when designing the GRC cladding panels.

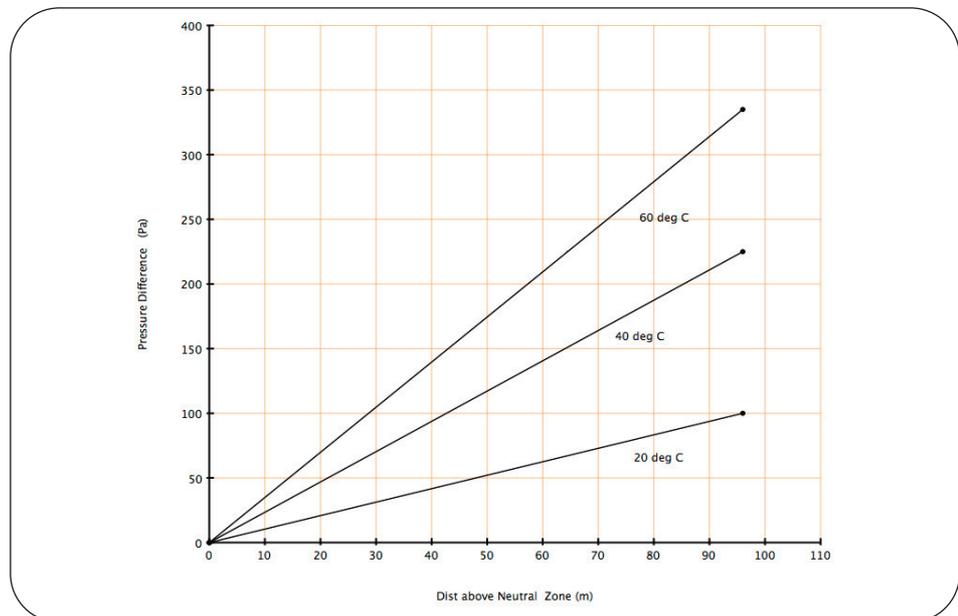


Figure 4. 30 - Effects of height and temperature on the 'stack'effect'

4.10 Fire resistance

GRC is non-combustable and does not emit smoke when exposed to a fire. Consequently, Architects and designers have greater flexibility in specifying components to satisfy fire performance requirements using GRC.

The GRCA, a Special Study Group within the Concrete Society, provides specialist advice on an International scale. Many Architects, designers and specifiers have sought guidance about the performance of GRC when exposed to fire. In an effort to produce more data, the Concrete Society commissioned Bodycote warringtonfire to carry out further fire tests on GRC samples made with and without adding polymer. Flame retardent additives were not used in the preparation of the samples. The results of these tests were published on 23 January 2008. All of the tests were carried out in accordance with the requirements of EN 13501-1 2007 (Clause 8).

Later in the year, numerous GRC cladding panels, in the form of box rib and stud frame construction, were 'tested' insitu when a fierce fire broke out in a new, prestigious hotel development in Dubai. GRC cladding panels covering the ornamental archway entrance to the Atlantis Hotel, Palm Jumeira in Dubai suffered fire damage on Tuesday, 2 September 2008. The seat of the fire was on the roof of the building in the entrance way at the base of the central arch, the main focus of the hotel complex.



Figure 4.31 - View of arch during construction showing GRC panels being painted



*Figure 4.32 -
General view of
site*



Figure 4.33 - View during the installation of the panels

NOTE

The smoke was created by the burning of the roof covering used for the entrance building - not the GRC panels.



Figure 4.34 - View of the fire shortly after it started

Urgent and detailed inspections yielded the following important findings:

- In the ribbed panels, the 15mm (average) thick areas between the ribs had burst outwards or inwards as a consequence of the fire. Clearly, these areas had been restrained by the ribs until the induced stresses became too great.
- Damage to the stud frame panels at high level was not evident from the inside.

- The GRCF panels had performed well in the fire, indicated by lack of damage to the supporting steelwork and miscellaneous flammable items lying on the cat walkways immediately behind the panels.
- Movements had occurred in the fixings, evidenced by the soot free areas adjacent to the washer plates. However, the fixings and support steelwork looked to be in good condition. Steel posts at the sides of the louvres at low level were badly buckled.
- Melting of several plastic shims and packers were apparent at the level immediately above the grills. This had allowed some rotation of one of the panels.
- Many of the ribs of the ribbed panels did not appear to have been compromised from the inside inspections. This was later disproved by the external inspections and sampling.
- Several holes had appeared in the ribbed panels between the ribs. Inspections confirmed that the heat damage was particularly extensive at the lower levels, resulting in delamination of the outside faces of the panels.



Figure 4.35 - Inside view of fire damage to box rib GRC cladding panels

The main damage was as follows:

- Delamination and holes in the panels were very evident at the lower levels.
- Bubbling and sagging of the paint skin was visible in many areas. Only sampling of these panels could ascertain if delamination had occurred.
- Rotation of one of the panels above the louvres was very obvious.



(a) Stud frame sample

(b) Box rib sample

Figure 4.36 - Delaminated samples of GRC panels

It soon became obvious that many of the panels at low level would have to be replaced with new GRC panels. Those at high level would be more difficult to inspect and sample. It was hoped that these panels had only been damaged by smoke or, at worst, by bubbling and sagging of the paint coating on the outside. Unfortunately, the first two samples taken indicated that some of these were delaminated to varying degrees and would have to be replaced. A total of 44 panels were identified as requiring replacement.

In view of the ferocity and extent of the blaze, the GRC panels performed extremely well in shielding the internal steel support system from fire damage. Another important consideration is that of fire stops at joints. The PCI publication 'Recommended Practice for Glass Fiber Reinforced Concrete Panels' (Third Edition) includes useful guidance on providing internal fire endurances up to 2 hours at joint positions by creating fire stops with ceramic fibre felt. Table 4.1 gives recommended depths (L in mm) of ceramic felt for various joint widths in mm.

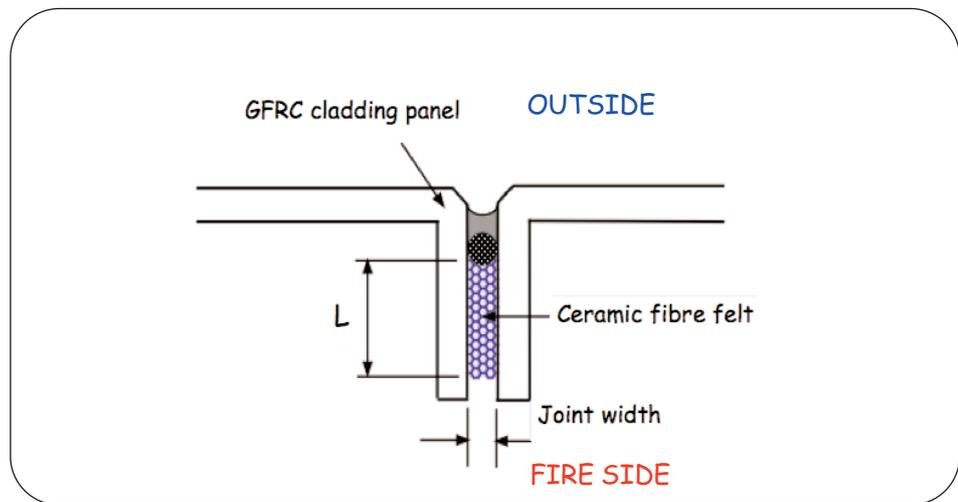


Figure 4.37 - Depth of ceramic fibre felt

Table 4.1

Fire endurance (Hrs)	Joint width (mm)	Length L (mm)
1	10	12
2	10	18
1	25	25
2	25	60

4.11 Digital Prototyping / Testing as Design Tool

The performance of fixing methods for GRC cladding systems can be investigated using digital prototyping and/or physical testing. Both of these can be expensive and time consuming. In many cases, testing may be the only reliable way to obtain reliable data for use in design, *eg carrying out wind tunnel tests to determine the magnitudes of wind loadings acting on GRC cladding panels on a complex, high rise building in an exposed location.*

Digital prototyping can complement and sometimes be used in place of physical testing. The former tends to cost less and can save significant amounts of time. Software packages like Inventor and Solidworks are able to analyse and 'design' 3D models of GRC panels and assemblies such as stud frame construction. It is not uncommon for the wind load intensities on a structure to be determined by wind tunnel testing and for the detailed design of the GRC cladding envelope to

be carried out using a suitable software package, like those mentioned above, using the output from the wind tunnel tests. The process of digital prototyping can be summarised as follows:

- determine concept(s)
- create and innovate
- validate
- manage designs
- manufacture

It is easy to see how this approach can be used to optimise new constructions like the hybrid stud frame construction described in Section 3 (see Figures 3.22 and 3.23).

An important finite element study of the 'Fire Resistance of Reinforced Concrete Beams using GRC Casting Formworks' was carried out by Fujita Naoaki of the Asahi Glass Co., Ltd., Res. Lab.) HIRAI TAKAYUKI (Nihombunrikadai) in 2001. He investigated the generation of tensile and shearing stresses at the interface between the inside faces of the GRC formwork and insitu concrete.

In the prototyping, he compared the performance of beams in fire conditions with and without GRC formwork. The inside faces of the GRC forms used in the tests were 'embossed' or covered with wire netting to enhance the bonding between the interfacing surfaces. Naoaki reported that the two types of beams, ie ones without and ones with GRC formwork, had a similar fire resistance when analysed using finite element theory. GRC permanent formwork is used extensively as permanent formwork in bridge deck construction. Its use in buildings is not as widespread but deserves more consideration, taking due account of all the cost parameters, not just material costs. The use of GRC permanent formwork for 'waffle' slabs is a case in point. Savings in material costs, if any, may be small but the cost savings in not having to erect and dismantle an extensive support system and remove waffle palletes should be considerable.

TYPES OF FIXINGS

5.1 Fixings into GRC

The most common type of fixing used to secure box rib and sandwich types of cladding panels to a structure is the stainless steel cast-in socket. It is usually anchored into the GRC panel by a transverse bar or bent end to spread the load over as large an area as possible (Figure 5.1).



Figure 5.1

NOTE Figure 5.3 shows a ribbed panel with six fixings. The lower central one should be 'fixed' whilst the other ones should be 'free' (see Figure 4.7(b)). The chamfers at the intersections of the ribs provide greater areas over which the fixing loads can spread thereby reducing concentrations of stress at the fixing

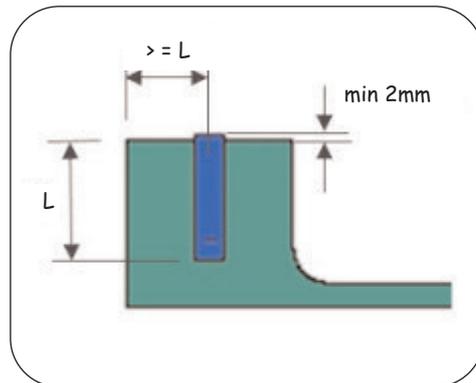


Figure 5.2

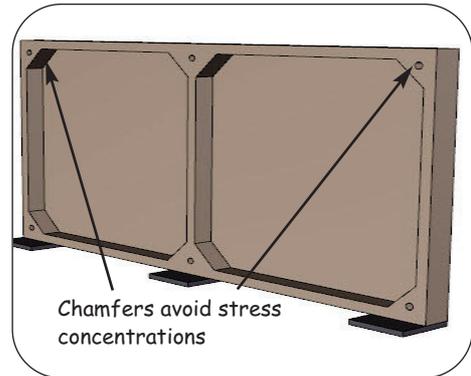


Figure 5.3

It is very important that cast-in sockets are encapsulated in an adequate volume of GRC with good fibre distribution around them. The ends of these sockets should be left slightly proud of the GRC as shown in Figure 5.2. This avoids the possible adverse effects of overtightening against the face of the GRC during fixing of the panel to the support structure.

The actual performance of cast-in sockets should be determined by carrying out representative tests. As a general rule, the socket should not be placed any

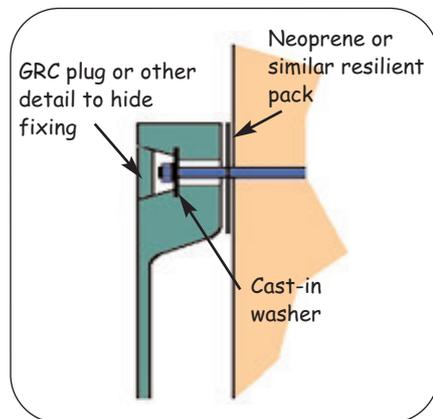


Figure 5.4 - Face fixing

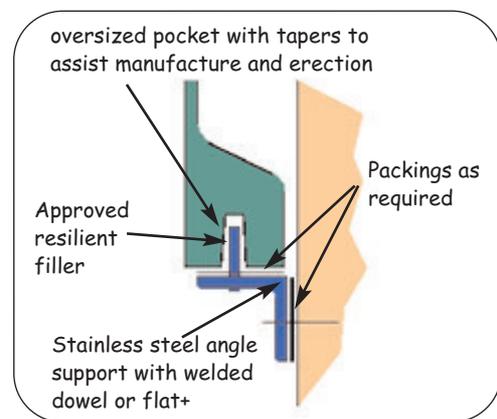


Figure 5.5 - Dowel fixing

nearer to the edge of the GRC than the overall length of the socket as also indicated in Figure 5.2.

As far as stress concentrations in the GRC are concerned, it is good design practice to adopt the chamfered details shown in Figure 5.3. This can also help in achieving the minimum edge distance to the socket.

Face fixing of the panels is sometimes used, particularly when access for fixing the panels is restricted and/or when the panels are very small (Figure 5.4). Instead of face fixing at the base of the panel, lateral restraint can be provided by dowels or flats as shown in Figure 5.5. This does not compromise the appearance of the panel. Unless face fixings can be hidden by surface features or patterns they can often become unsightly.

Fixings in the form of bent bars or bent flats can be bonded to the back of a GRC panel as illustrated in Figures 5.6(a) and (b). These are only suitable for relatively small panels, as they are not anything like as strong as the cast-in sockets described above. The fixing shown in Figure 5.6(a) is similar to that used for flex anchors in stud frame construction.

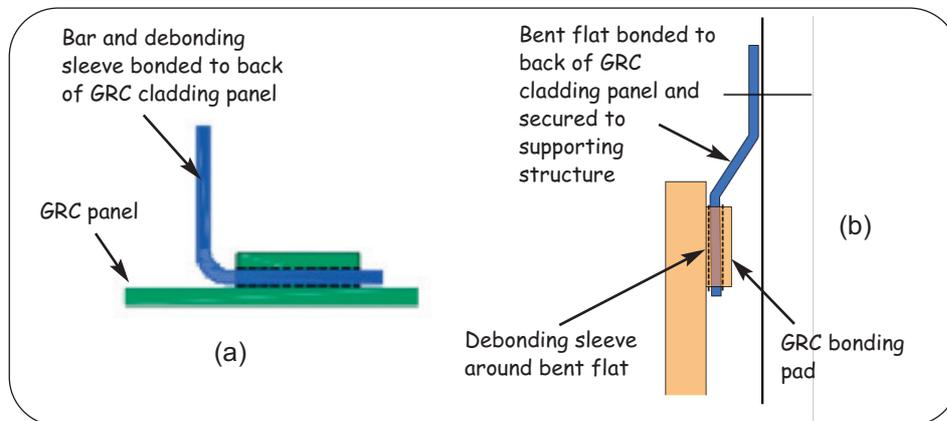


Figure 5.6 - Bonded fixings

Lastly, two types of unbonded fixings that are in common use are shown in Figures 5.7(a) and (b). The one illustrated in Figure 5.7(a) is usually used to provide lateral restraint at the tops of cladding panels. The bent steel flat is located in a longitudinal slot cast into the GRC panel and secured to the supporting structure. The type illustrated in Figure 5.7(b) is often used to fix lightweight cornice type features to the outsides of buildings as indicated in Figure 5.8. A special unit with orthogonal slots may be used to complete the fixing (Figure 5.8).

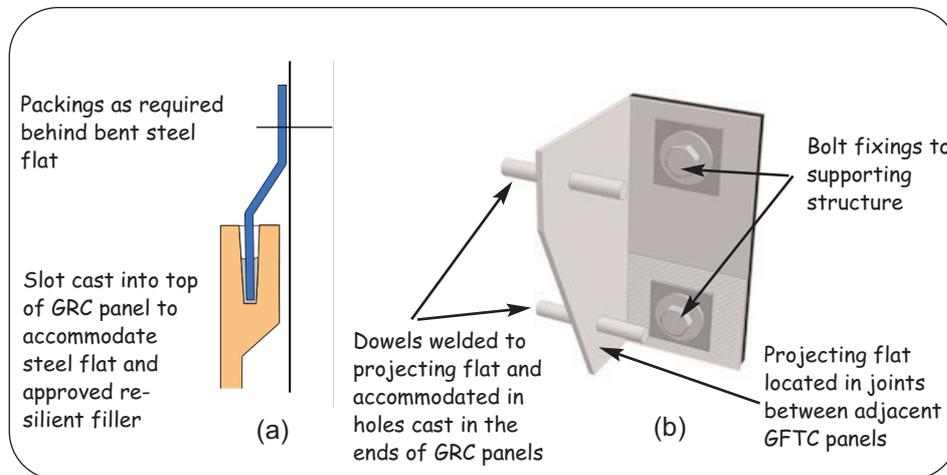


Figure 5.7 - Fixings into GRC panels

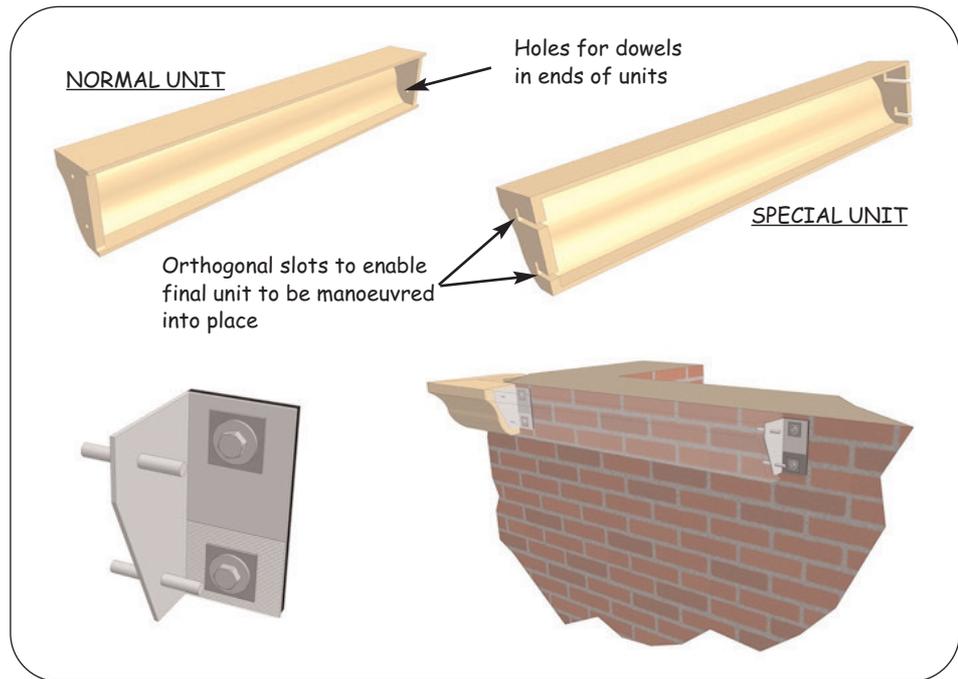


Figure 5.8 - GRC cornice construction

There are several other fixing systems that employ the same basic method of fixture. Three of these are presented in Figures 5.9, 5.10 and 5.11. The fixture illustrated in Figure 5.9 shows how a metal to metal, dowel type fixing can be achieved. The advantage of this method is to ensure that the dowel connection is visible and more positive than a GRC to metal connection. Slots formed in the GRC unit that are designed to accommodate a dowel or flat metal connection are acceptable in theory, but if there is any significant out-of-tolerance found on site, there is a tendency to enlarge the slot in the GRC to compensate, with the possibility of it becoming unsafe. As with other bonded connections, this connection should be tested to confirm its ultimate capacity.

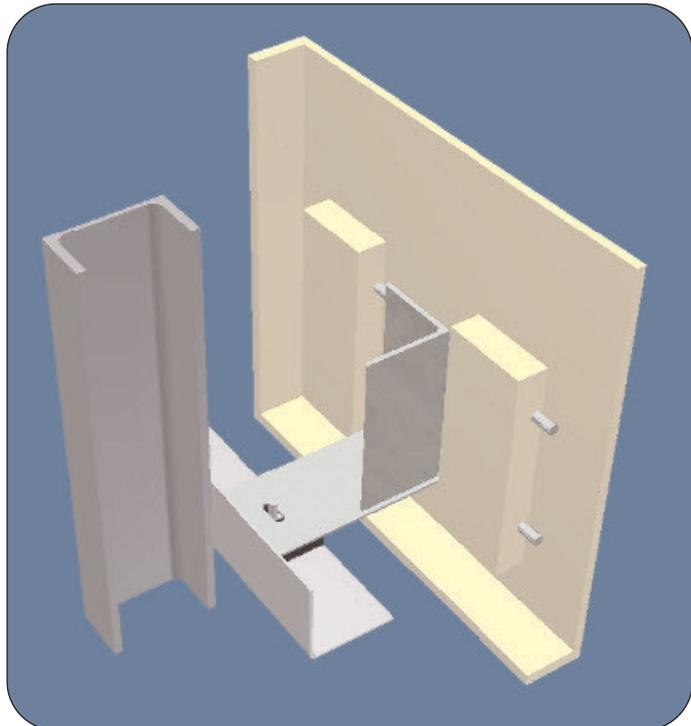


Figure 5.9 - Bonded fixing to form seating at base of panel

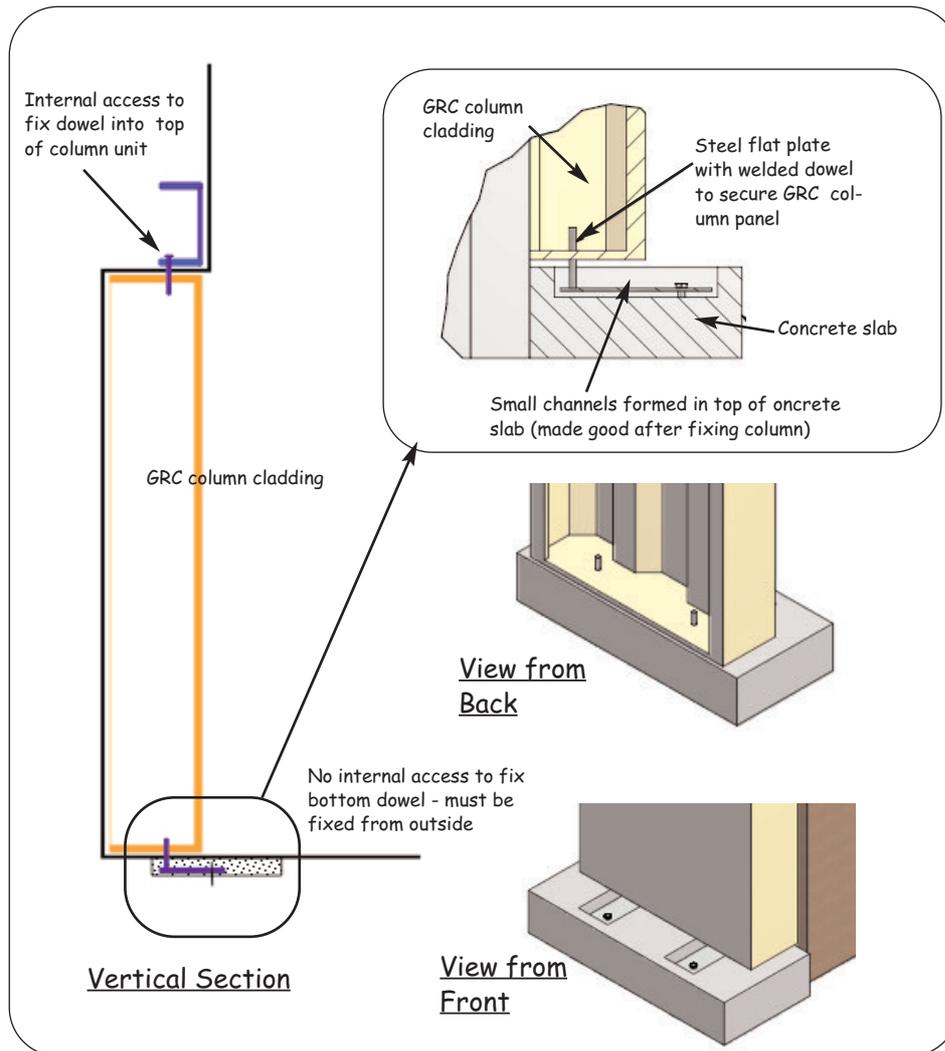


Figure 5.10 - Overcoming problem of no headroom to lift GRC column over bottom dowel

The scenario represented in Figure 5.10 is intended to flag up a mistake that is made all too often in detailing GRC cladding panels. When dowel connections are used, it is important to ensure that there is significant headroom for the unit to be lifted up over the dowels at the base of the unit. This requirement seems obvious, but this common mistake can result in high costs for remediation. In the situation shown in Figure 5.10, the small gaps at the top and bottom of the cladding panel can be achieved by using small channels in the concrete plinth at the base of the unit. These channels can be filled in with a mortar or small aggregate mix after installing and aligning the GRC unit.

Finally, Figure 5.11 illustrates how GRC column units can be fixed using dowels at the top *and* bottom of the unit. Note the small diameter diagonal, stainless steel bars bonded into each inside corner, this strengthens the sides and ensures good alignment at the vertical joints.

The use of dowel fixings at the tops of GRC panels is a very effective and economic way of providing lateral restraint whilst allowing full freedom of movement for shrinkage, thermal and moisture effects.

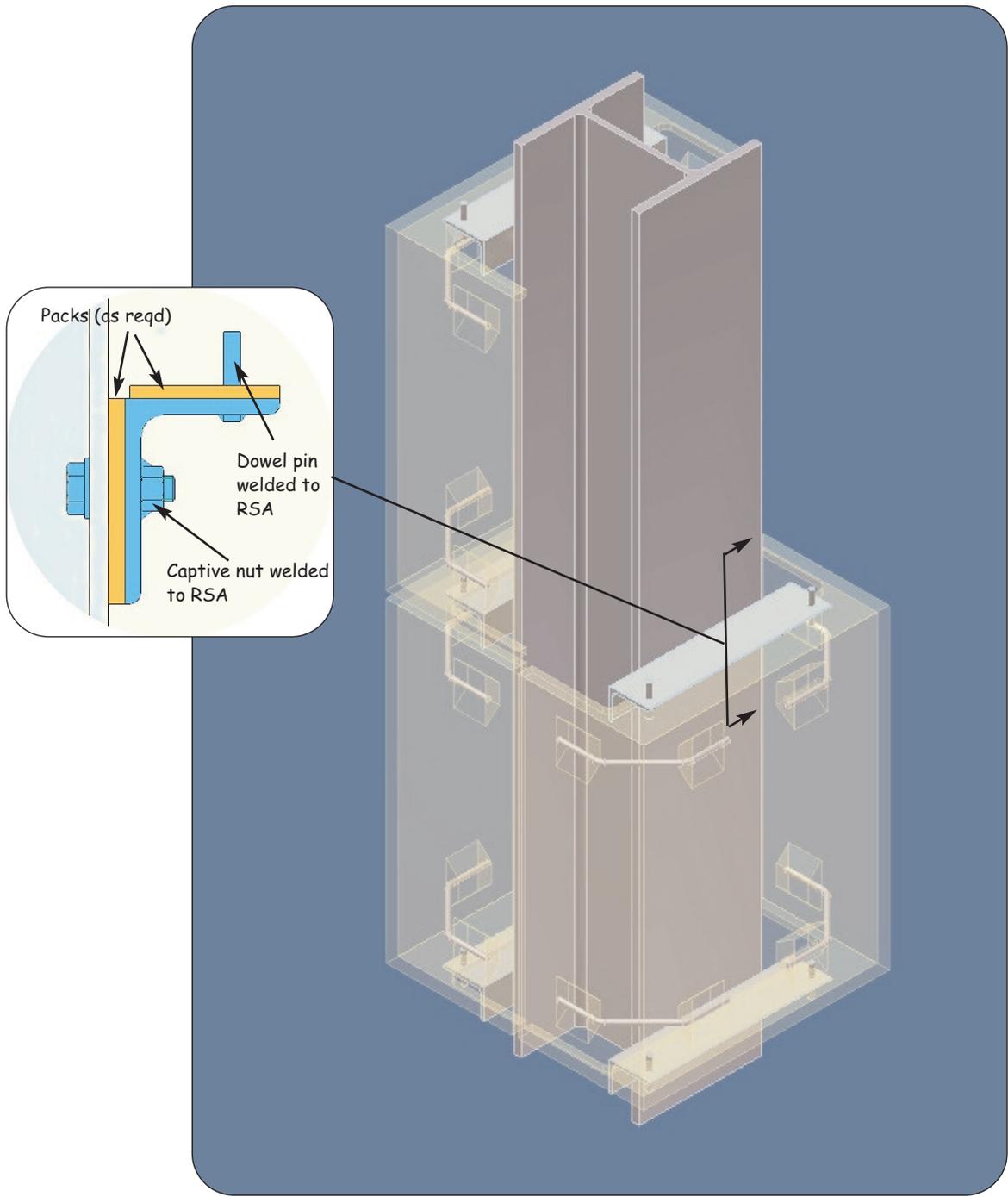


Figure 5.11 - Dowel connections at the tops & bottoms of GRC column cladding units



Figure 5.12 - Expansion fixing



Figure 5.13 - Resin anchor fixing

5.2 Fixings to Supporting Structure

5.2.1 Concrete Structures

Fixing into concrete is usually achieved by expansion fixings, resin fixings or cast-in fixings. Care is needed to ensure that each type of fixing is installed strictly in accordance with the manufacturers instructions.

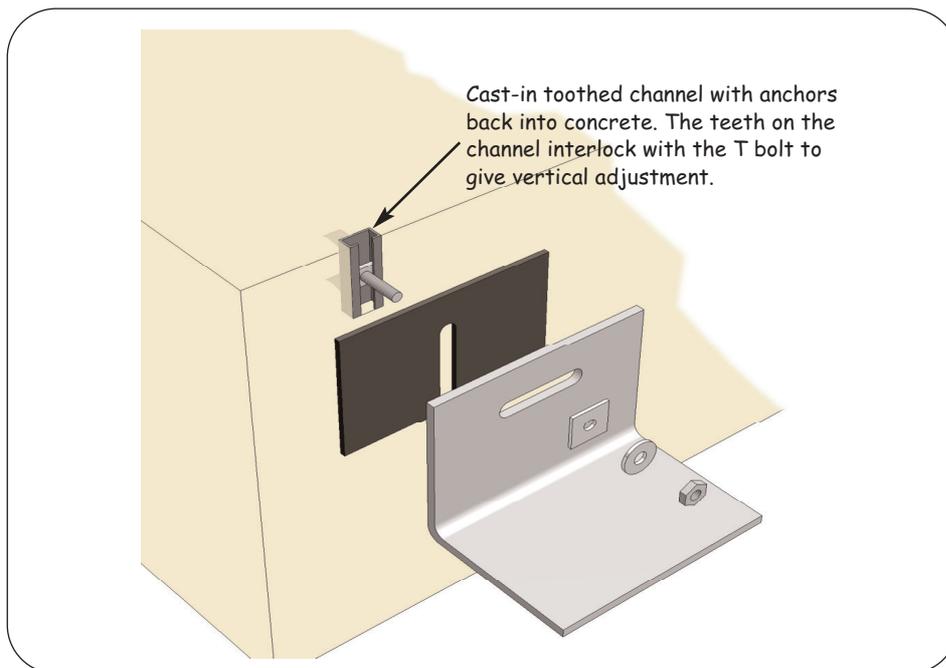


Figure 5.14 - Cast-in toothed channel fixing

a. Expansion Fixings (Fig 5.12)

When these are tightened, a sleeve is forced along a cone or a pair of cones into the surrounding concrete. The fixing holds by a combination of keying and friction.

b. Resin Anchor Fixings (Fig 5.13)

Resin fixings rely on the ability of the resin to transmit the force in the steel rod by bond into the surrounding concrete. These fixings can be used closer together and at closer edge distances than expansion bolts. The time taken for the resin to set and the fixing to achieve its working strength will vary according to the ambient temperature. Basically, the two part resin is contained in a thin glass tube. This tube is inserted into the drilled hole and broken by inserting and rotating the threaded rod.

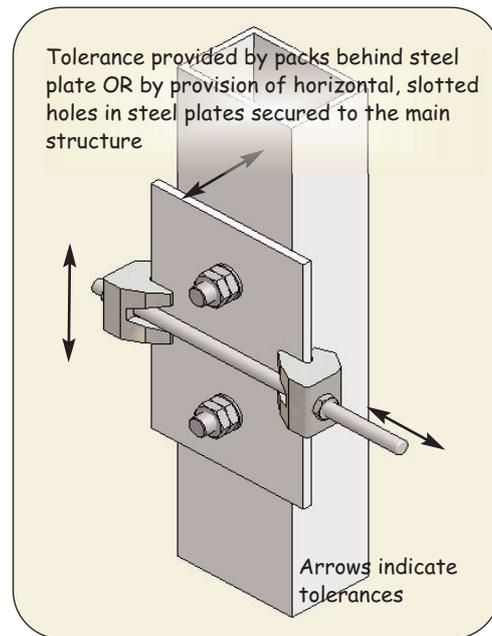


Figure 5.15 - Clamp fixing



Figure 5.16 - Hollo bolt

c. Cast-in Fixings (Fig 5.14)

These are generally channels with anchors fixed to the back and are cast into the concrete. In conjunction with 'T' head bolts, these fixings allow the fixing position to move along the length of the channel. Channels can be used at close centres and at closer edge distances than other fixings.

It is recommended that cast-in channels are used wherever possible. These allow greater adjustment, can be positioned around the reinforcement and used closer to the edge of the concrete. Cast-in fixings are also more effective when used in the tension zone of reinforced concrete beams.

5.2.2 Steelwork Structures

Fixings are usually bolted to structural steelwork, through pre-drilled holes or holes drilled on site, though welding is sometimes used to fasten fixing components to support steelwork. In certain circumstances, clamp fixings can be used to provide simpler connections with increased tolerances and financial benefits (Figure 5.15). The hollo bolt shown in Figure 5.16 enables connections to be made through a single skin in the support structure. It would be suitable for the bolting arrangement shown in Figure 5.15, particularly if access to the opposite, outside face of the hollow section is prevented.

5.2.3 Brickwork & Blockwork

It is not advisable to fix a GRC cladding system on a brickwork/blockwork wall system unless:

- (a) the panels are very small,

and

- (b) the wall construction has been reinforced and specifically designed to support the GRC panel system,

Clearly, if the panels are small, the resulting wind load and eccentric self-weight

of the panels transmitted to the wall construction can be assumed to be uniformly distributed. However, large panels transmit these loads through the fixings at wider spacings. Consequently, the loads acting on the wall construction are more like a series of discreet point loads and will, therefore, have a greater destabilising effect on the wall construction.

Fixings for GRC cladding panels on a brickwork/blockwork type wall construction should be fixed to the bricks, *not* in the mortar joints. Furthermore, epoxy resin fixings should be used, as any expansion type of fixing is likely to split or damage the brickwork. These fixings should be spaced in accordance with the manufacturers recommendations.

Last, but certainly not least, the hole into which the resin capsule will be placed should be lined to prevent the resin from escaping into vertical holes formed in the brickwork or into the cavity between brickwork and blockwork, Suitable tubular, linings are provided by manufacturers for this purpose.

5.2.4 Fibreglass Pultrusions

The following illustrations indicate good practice when using pultruded profiles to construct support structures. In each case, part Figure (a) illustrates the perceived problem whilst part Figure (b) indicates a possible remedy. Clearly, these do not show all possible cases, but the common theme of each is to avoid loading the section, or parts of the section, in the weakest direction. Always aim to load the section in its strongest direction, the pultrusion. Some manufacturers do issue safe load information for the strength of members loaded at angles (> 0 deg to < 90 deg) to the pultrusion, but extreme care must be taken when using this information.

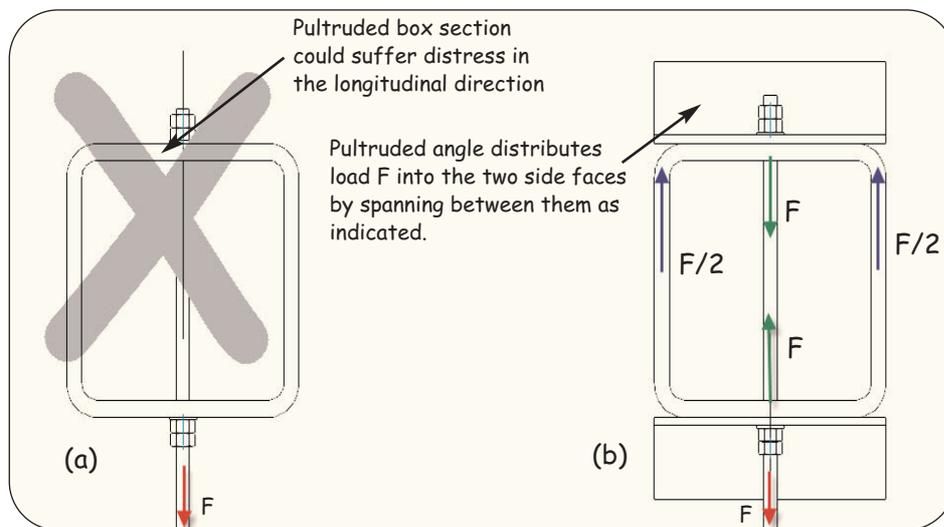


Figure 5.17 - Avoidance of possible damage to pultruded box section

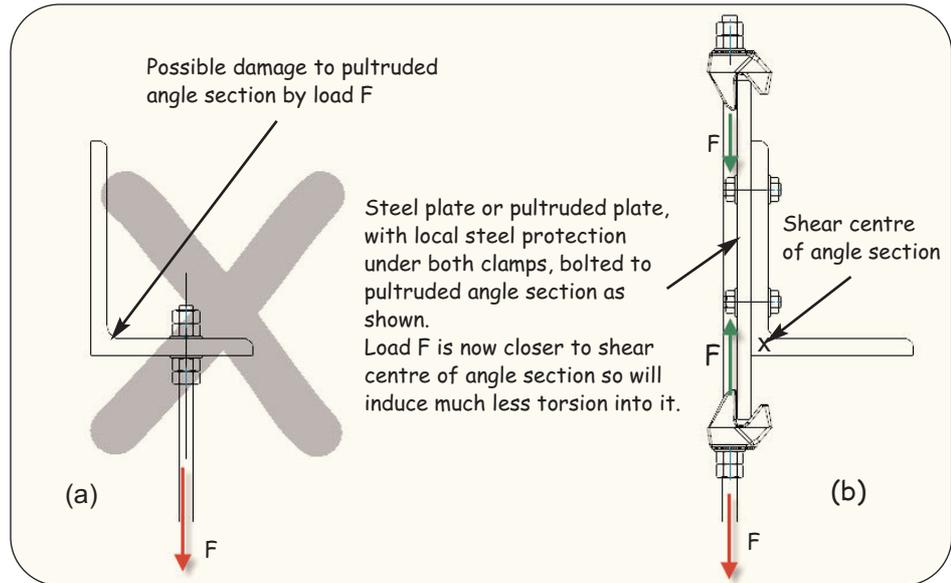


Figure 5.18 - Avoidance of possible damage to pultruded angle section using clamps

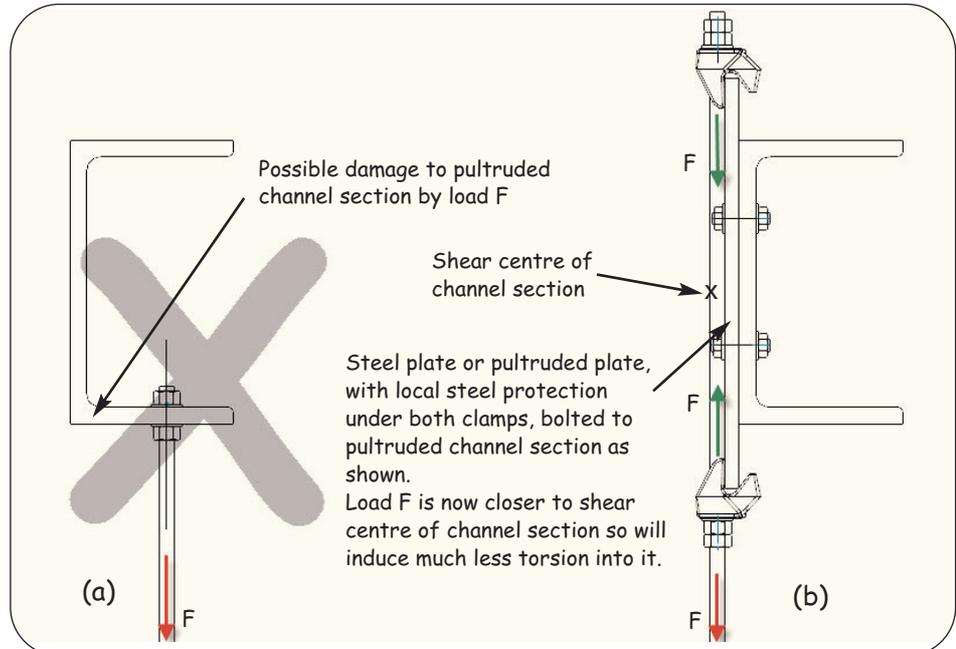


Figure 5.19 - Avoidance of possible damage to pultruded channel section using clamps

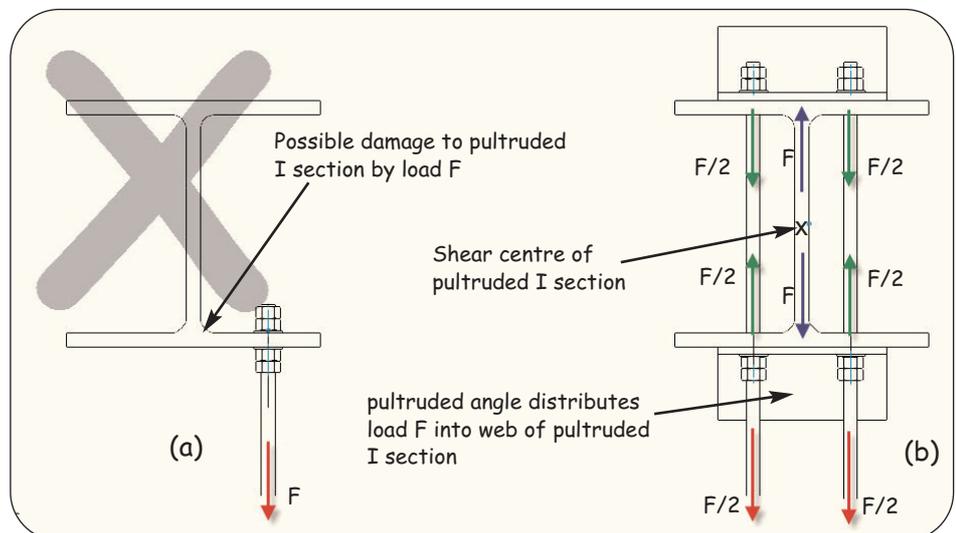


Figure 5.20 - Avoidance of possible damage to pultruded I section

The sectional views shown in Figures 5.17 to 5.21 could be a horizontal section through a column or a vertical section through a beam. All of the descriptions that follow could apply to either case. Equally, the load F could also act in the opposite direction to that shown.

In the fixing arrangement shown in Figure 5.17(a), the bolted connection through the pultruded box section can cause local damage to the bolted faces. These faces tend to span between the other two faces of the box section; unfortunately, the strengths of the bolted faces in this direction depend mainly on the strength of the resin not the strength at right angles which is enhanced by the pultrusion process.

The introduction of the pultruded angles, shown in Figure 5.17(b), relieves the bolted faces of the box section and transfers the load F directly to the other two strong faces.

The remedy shown in Figure 5.18 using clamps also gives it adjustability i.e. more tolerance as well as inducing less torsion into the pultruded angle section. A similar situation is illustrated in Figure 5.19 with a pultruded channel section.

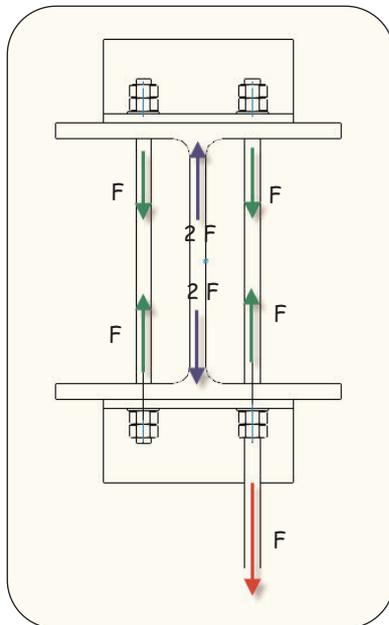


Figure 5.21 - Eccentric loading of a pultruded I section

Again, the load F is applied closer to the shear centre of the section thereby reducing the torsion on the section.

An interesting situation arises out of the bolted assembly shown in Figure 5.20. The introduction of pultruded angles on the top and bottom flanges of the I section transfers the load to the central web. Using two bolted connections ensures that resultant load F acts through the shear centre of the I section. If the load F must be eccentrically applied as indicated in Figure 5.20(a), the other bolted connection can be curtailed as shown in Figure 5.21. However, due consideration of the statics shows that the resultant load in the central web is now increased to $2F$.

In summary, pultruded profiles offer many advantages in using them to construct support structures for GRC components. Nevertheless, great care must be taken to ensure that their anisotropic characteristics are fully considered in the design process.

The other important consideration is that of deflection. A pultruded member will deflect approximately 10 x that of a corresponding steel member carrying the same load over the same span. This need not become a problem if bracing can be introduced, or if the form of the support structure can be changed to avoid the problem in the first place.

6.1 Introduction

GRC panels cannot be produced to an exact size nor can buildings be constructed precisely to line and level. Consequently, a degree of tolerance should be incorporated into fixing systems for cladding panels to avoid fixing problems on site. It is also essential not to use movement allowances in fixing components as tolerance. When the panels are finally fitted, the movement allowances are required to avoid possible distress to the GRC panels. The designer should refer to BS 5606:1990 and relate the specified tolerances of the support structure to tolerances required for the cladding panels. However, it is not always possible to allow for the combination of building movements, panel movements and worst tolerances, as this would result in unacceptably wide joints between the GRC panels. In such cases, an accurate site survey would enable the designer to address these problems, mainly by customising the panels and/or fixings. Notwithstanding this, some reliance must also be placed on the skills of the erection team to overcome tolerance difficulties on site.

6.2 Manufacturing Tolerances

Tolerances for GRC panels should be specified in the Contract Documents. As with other cladding products, tolerances for manufacturing and erection of GRC cladding panels should be established and adhered to. If any dimensions fall outside these tolerances, the following adverse and detrimental conditions could result:

- a) eccentric loading conditions
- b) reduction of bearing areas with the consequence of distress to the GRC panel
- c) fixing problems
- d) unacceptable aesthetic variations
- e) delays in fixing and completion of the works
- f) interfacing problems with other constructions and violation of property lines.

Whilst it is usually unacceptable to exceed the specified tolerances the cladding works may still be acceptable. This will depend upon views taken by the design professionals after they have had time to consider all of the ramifications of the tolerance(s) being exceeded.

Manufacturing tolerances for GRC panels are generally determined by economic and production considerations. Tolerances should not be too stringent as this could result in unacceptable costs and delays.

In general, manufacturing tolerances should be within the following limits:

- | | | |
|----|--------------------------------|--|
| a) | Moulded faces $\leq 3\text{m}$ | $\pm 3\text{ mm}$ |
| b) | Moulded faces $>3\text{ m}$ | $\pm 3\text{ mm per } 3\text{ m with max of } 6\text{ mm}$ |
| c) | Edge returns | $+ 12\text{ mm } - 0\text{ mm}$ |

- d) Thicknesses
 - i) Architectural facing thickness ± 3 mm
 - ii) backing mix + 5 mm - 0 mm
 - iii) depths of integral ribs + 10 mm - 5 mm
- e) Angular variation of side moulds ± 1 mm in 75 mm
- f) variations from square
difference in lengths of diagonals or other similar criteria
3 mm per 2 m or 6mm whichever is greater.
- g) bowing $\leq L / 250$
- h) openings within panel face ± 5 mm
- i) location of opening within panel ± 3 mm
- j) Stud frames should be fabricated within the following tolerances:
 - i) vertical and horizontal lengths alignments 6 mm in 3 m
 - ii) spacing of framing members ± 10 mm
 - iii) squareness of frame (difference in diagonals) 10 mm
 - iv) overall lengths of frame ± 10 mm

It may be necessary to adjust the jigs used to fabricate the stud frames, prior to the frames being galvanised, to offset some of the distortions due to the galvanising process.

6.3 Erection Tolerances

Erection tolerances are dependent upon the type of structure being built, whether it is steel, concrete framed or load bearing construction, tolerances for cast insitu concrete frames should be generous and as large as possible consistent with the Architect's aesthetic requirements.

Any major discrepancies can often be highlighted by carrying out accurate site surveys before final detailing begins.

When supporting the GRC panels on steel beams, care should be taken to not induce excessive torsional stresses into them.

Sufficient tolerances must be provided between the GRC cladding panels and other interfacing constructions, eg glazing, at all joints between them. Early discussions between the GRC designer and the designer of the other constructions should avoid difficulties at a later date. The order in which the different constructions are erected is also very important. If GRC panels have to be left to last, they may have to be face fixed to the structure, thereby creating aesthetic problems.

6.4 Adjustments

Adjustments will be required in all three planes, x, y and z. The degree of adjustment necessary will depend on the type of structure, individual tolerances (structures and GRC panels), site control and the overall finished tolerances to be achieved.

6.4.1 Angle Support Brackets

Adjustments in the fixing of angle support brackets may be provided in several ways as follows:

In-plane adjustment can cause problems on site. A minimum bearing area of GRC on the support must be maintained to avoid distress to the GRC. Packing shims (plate or horseshoe washers) should generally be limited to a maximum thickness of 12mm. Packs should be positioned such that their lower end is at or below the start of the bend in the plate as indicated in Figure 6.1.

Oversized holes in conjunction with serrated washers provide multi-directional adjustment with a positive lock. Packing shims are used to provide in-plane adjustment as shown in Figure 6.2.

Horizontal slotted holes facilitate lateral adjustment. Vertical adjustment can be provided by fixing the angle slightly low and seating the cladding on two or more PTFE packs as indicated in Figure 6.3.

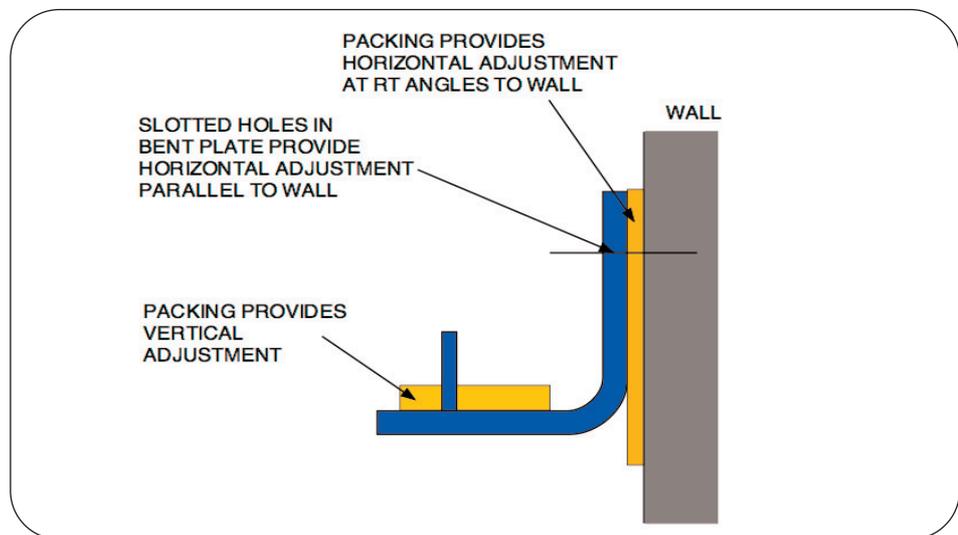


Figure 6.1 - Packing shims

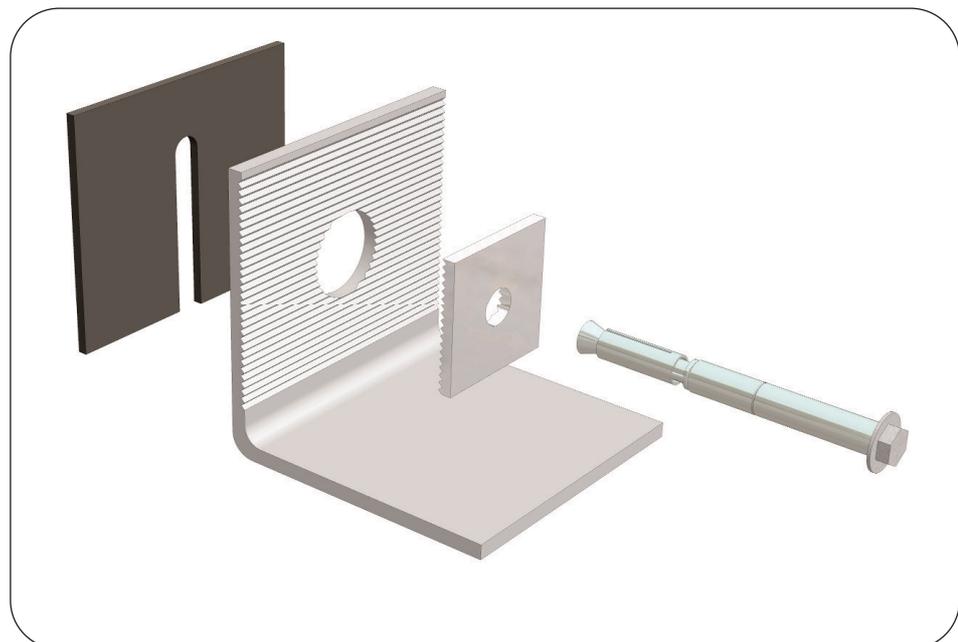


Figure 6.2 - Use of serrated washers

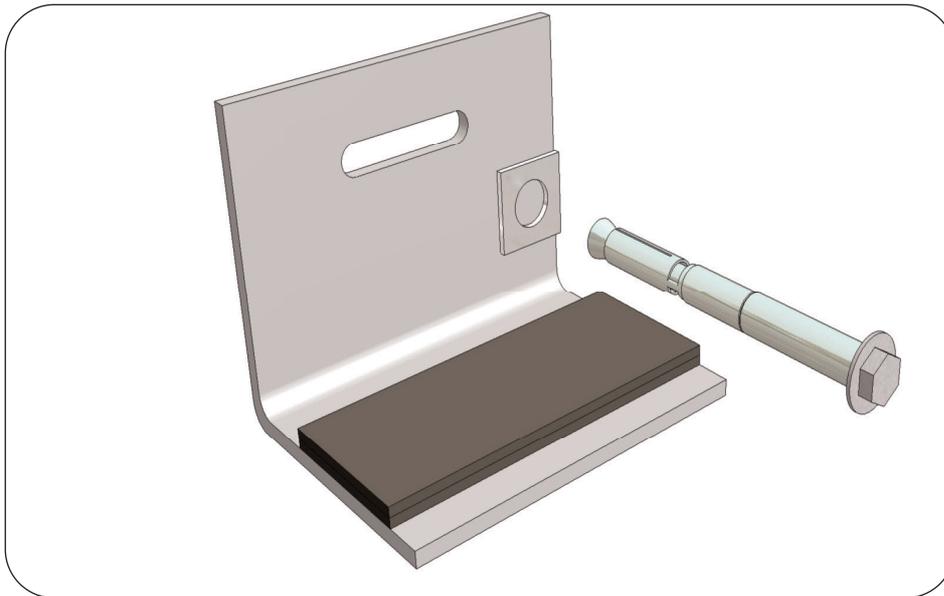


Figure 6.4 - Use of horizontal, slotted hole & packs

Channel fixings anchored to the backing support can provide considerable fixing adjustment in one direction only (vertical or horizontal). A toothed channel should be used to provide vertical adjustment and a positive lock. In this case, horizontal slotted holes in the angle provide the necessary horizontal adjustment. Packing shims are used to provide in-plan adjustment as shown in Figure 6.5. Angle support brackets may incorporate dowels or welded flats to provide lateral restraint to the GRC panels as indicated in Figures 6.6 and 6.7. The welded flats spread the stresses induced by transverse loads over a wider area than the dowel connection. However, the latter is more forgiving if there are any inaccuracies with the fabrication of the fixing. A badly misaligned flat will obviously create more problems on site than a misaligned dowel. Incorrect fixing of angle supports, as shown in Fig 6.8, can result in bearing problems. Angle supports with only one fixing bolt are to be preferred as they take less time to fix and have the capacity to rotate and provide the intended bearing area.

Vertical packing should extend beyond bearing area behind bent plate as shown

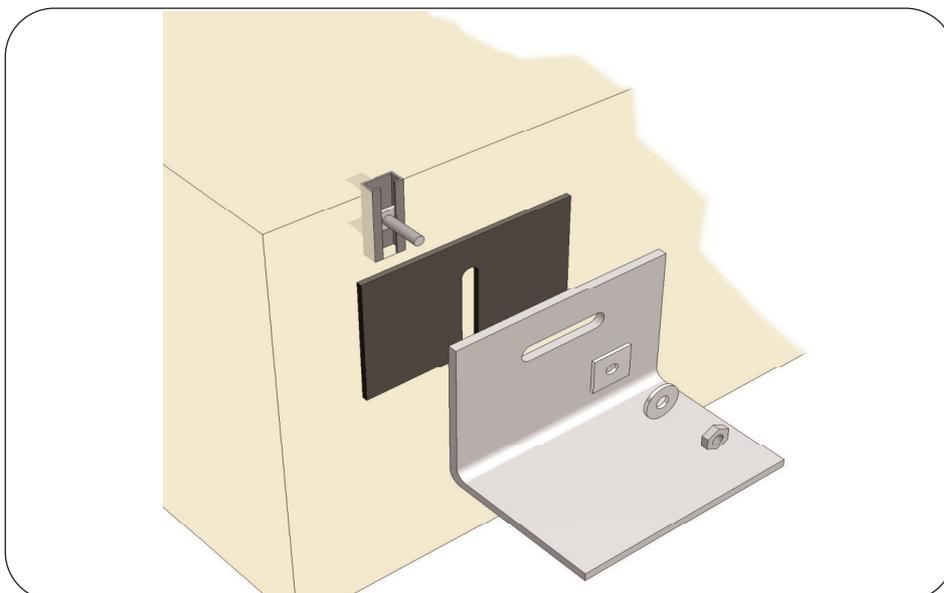


Figure 6.5 - Use of toothed channel and slotted hole

NOTE
An approved resilient filler can be used to partly fill the dowel slot. This stabilises the fixing but does not hinder any in-plane movements of the panel

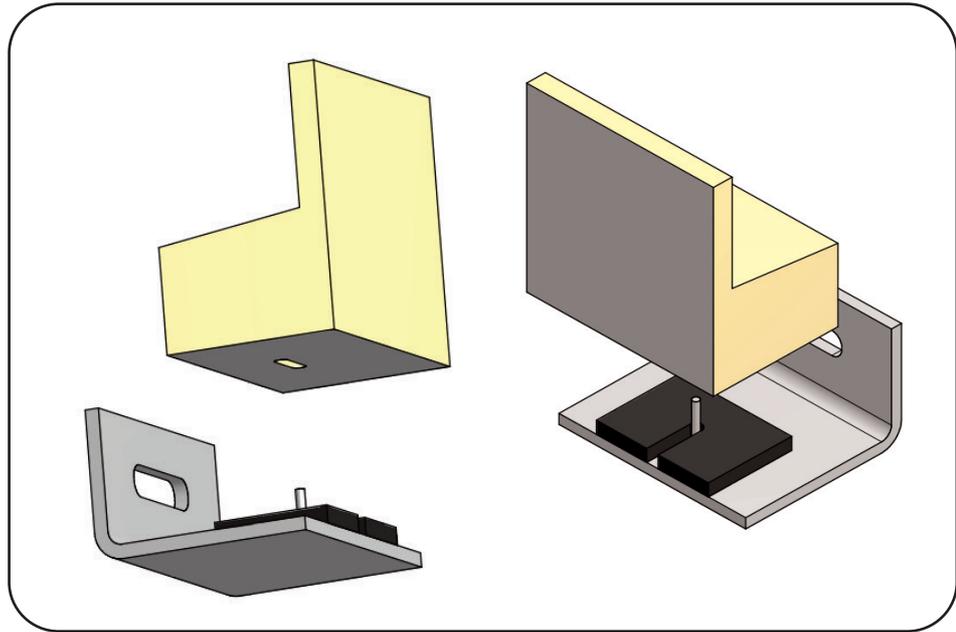


Figure 6.6 - Angle support bracket with dowel connection

NOTE
The slot in the bottom of the GRC panel can be local or continuous.

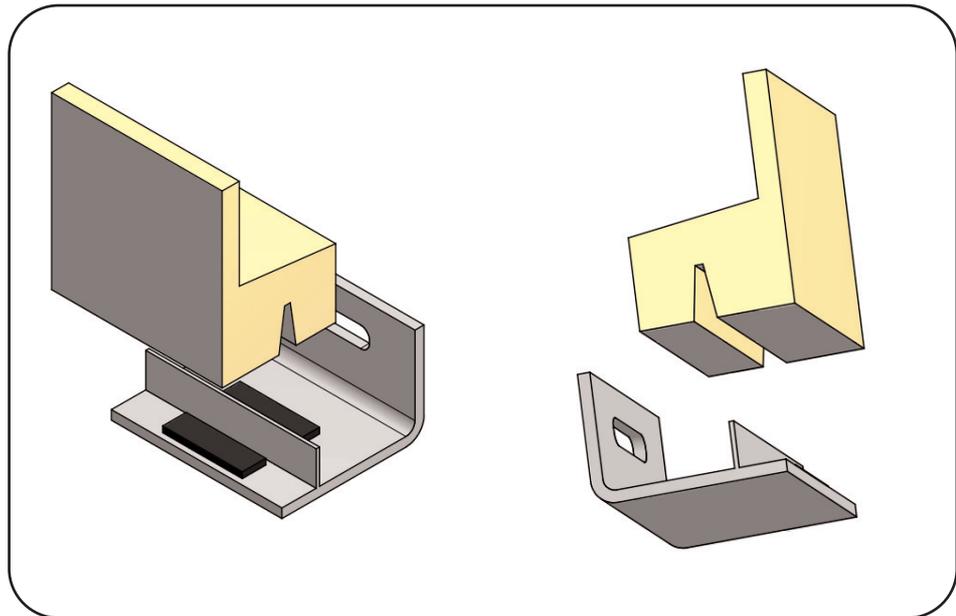


Figure 6.7 - Angle support bracket with flat connection

Reductions in bearing from using undersize packings can result in excessive bearing pressures and possible distress to the GRC (Figure 6.9). The combined fixing shown in Figure 6.10 is sometimes used for lighter GRC panels. It does not, however, allow independent horizontal and in-plane adjustments of upper and lower panels.

An alternative, preferred detail which does allow separate adjustment of the upper and lower panels is shown in Figure 6.11.

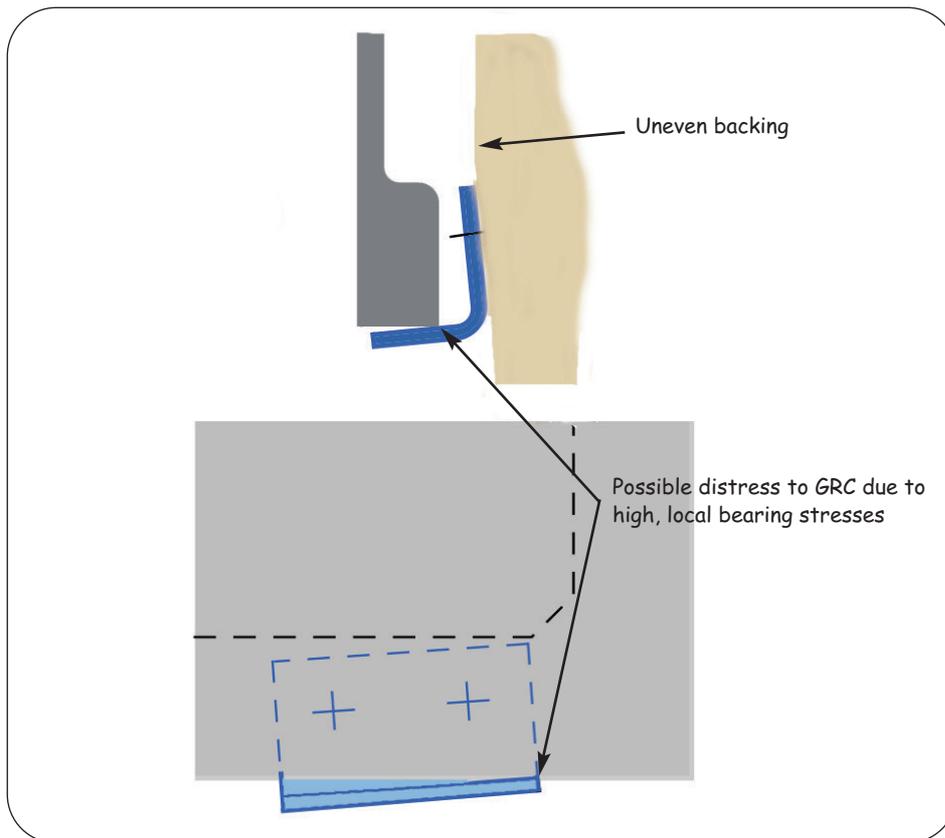


Figure 6.8 - Incorrect fixing of seating cleats

NOTE
Possible distress to GRC in bearing.
Can occur when backing is uneven as indicated.

NOTE
Angle supports with only one fixing bolt are to be preferred as they take less time to fix and have the capacity to rotate and provide the intended bearing area. Again, there is a risk of distress to the GRC in bearing by the misaligned support angle indicated.

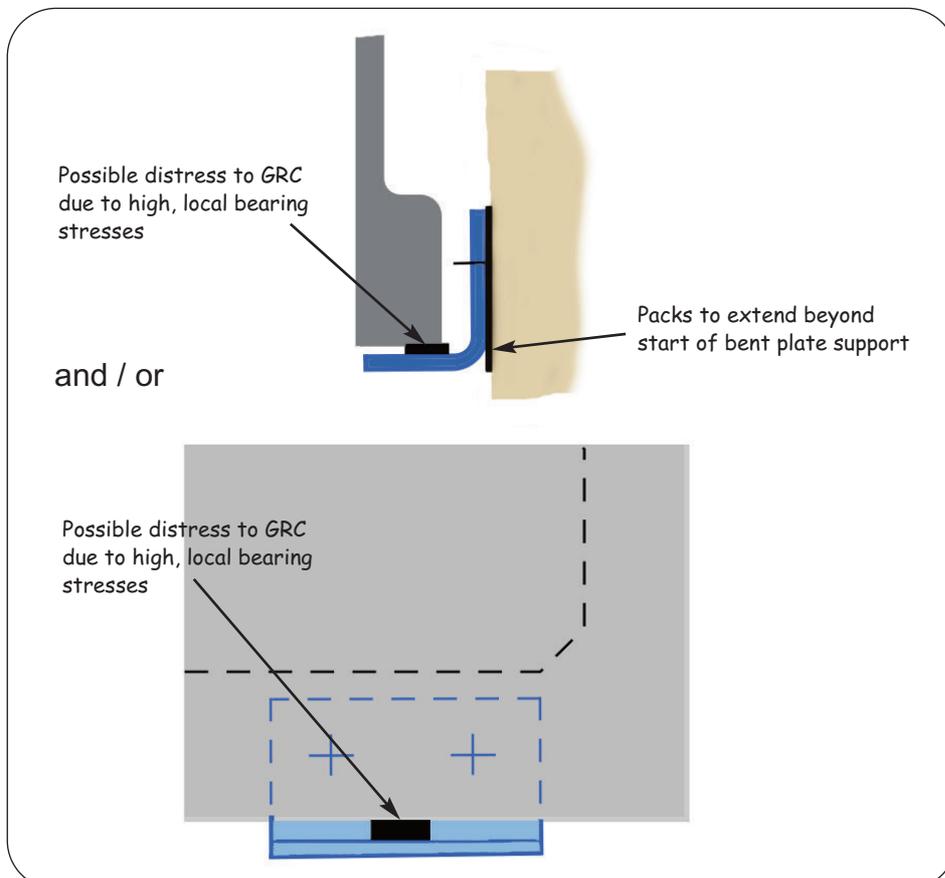


Figure 6.9 - Problems with undersized packs

NOTE
Reduced bearing areas for both horizontal & vertical packs. The inadequate horizontal pack may result in distress to the GRC.

NOTE
Inadequate packing can result in high bearing stresses in the GRC.

NOTE
The panels do not have independent horizontal adjustment.

Bad packing can result in rotating of s/s angle support and distress to the GRC.

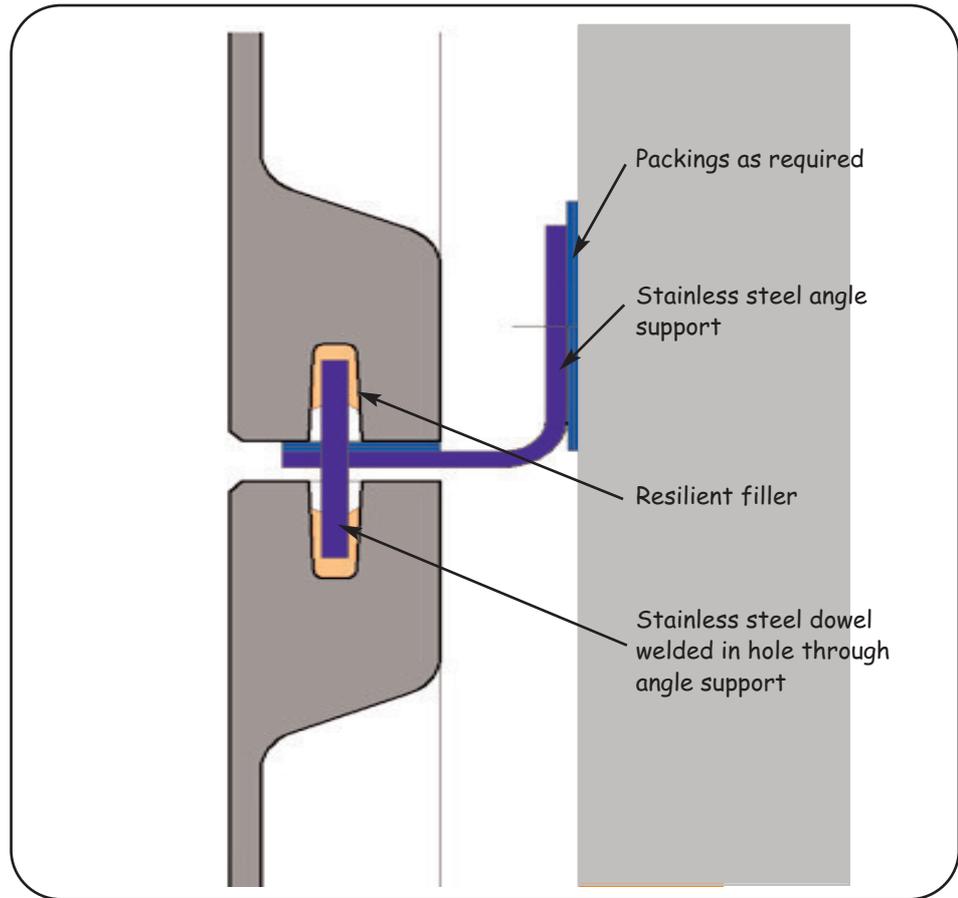


Figure 6.10 - Combined fixing

NOTE
This type of fixing allows independent horizontal adjustment of upper and lower panels.

Bad packing can result in rotation of s/s angle support- and distress to the GRC.

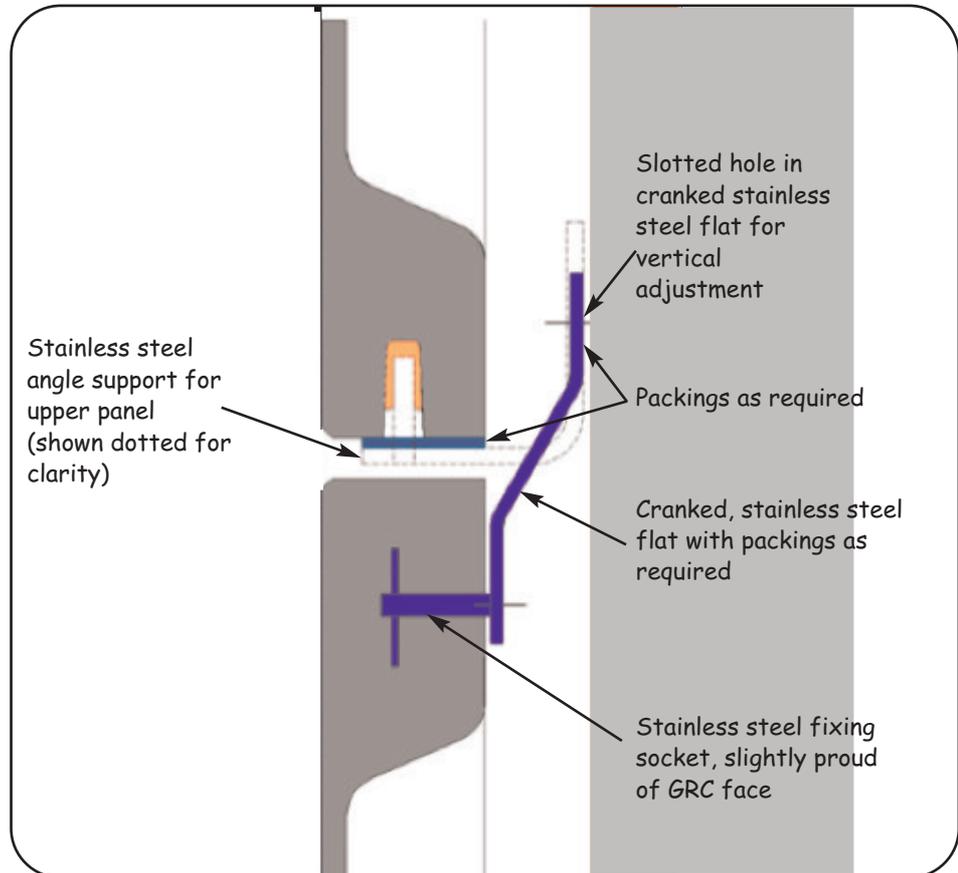


Figure 6.11 - Separate fixings

6.4.2 Restraint Fixings

Details of typical restraint fixings are shown in Figures 6.12 (at the top of the GRC panel) and Figure 6.13 (at the bottom of the GRC panel).

In the top fixing (Figure 6.12), the cast-in socket should be slightly proud of the GRC surface to ensure that forces applied during tightening cannot pull it out. Tolerances can be provided by the use of packs and oversize holes. Isolation of the mild steel and stainless steel components, to prevent any galvanic corrosion, is ensured by the use of PVC tubes and PTFE washers.

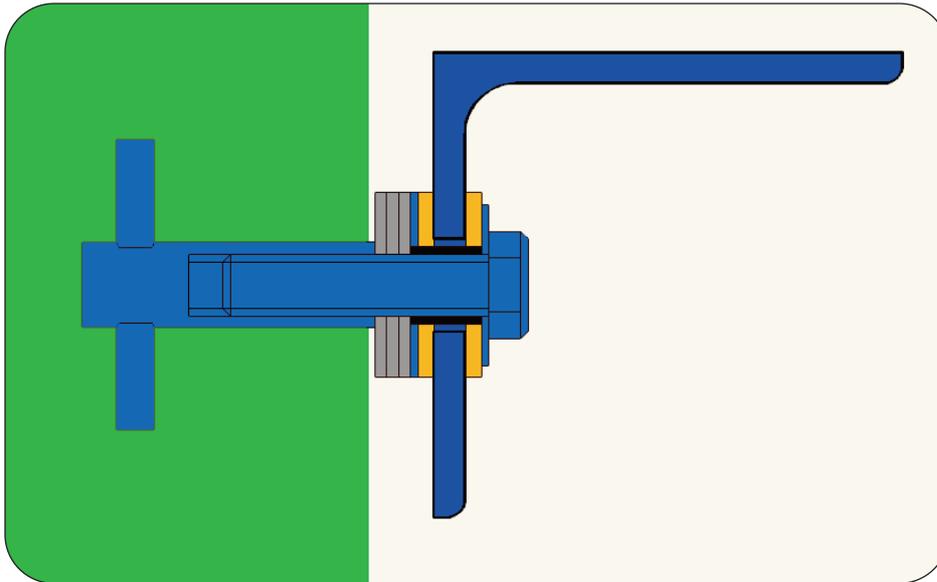


Figure 6.12 - Restraint fixing at the top of the panel

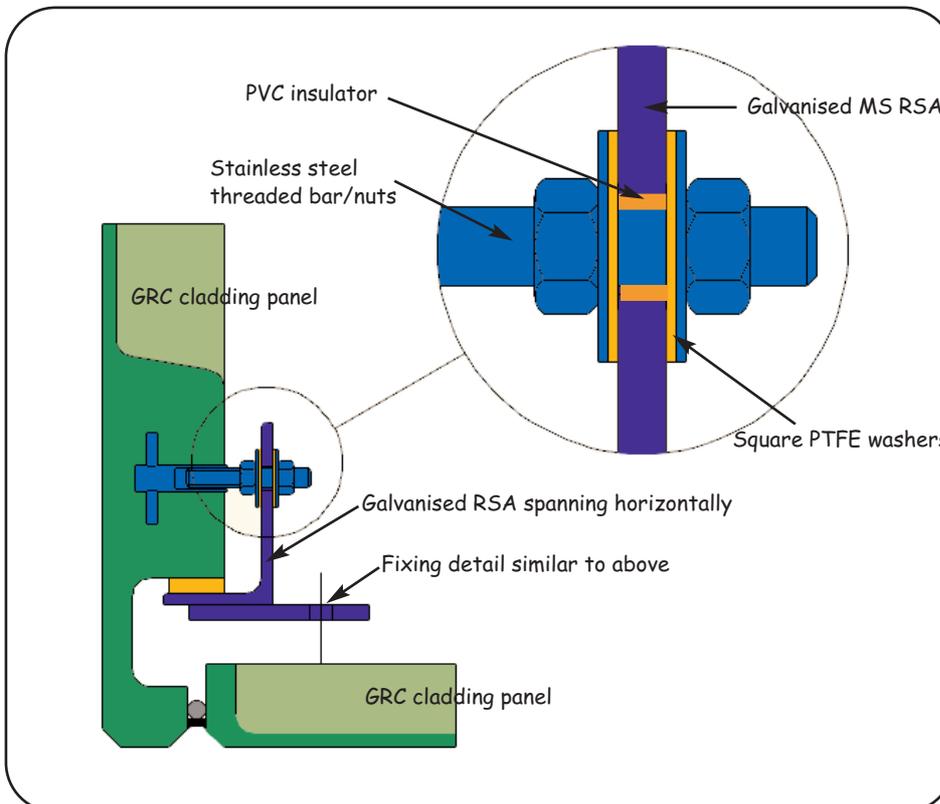


Figure 6.13 - Restraint fixing at the bottom of the panel

The bottom fixing (Figure 6.13) provides lateral restraint and supports the weight of the panels. Tolerances are again provided by the use of packs and oversize holes. Isolating tubes and washers are required to prevent the possibility of galvanic corrosion.

A combined fixing which provides seatings, lateral restraint, good tolerances and freedom of movement for the GRC panels is illustrated in Figure 6.14.

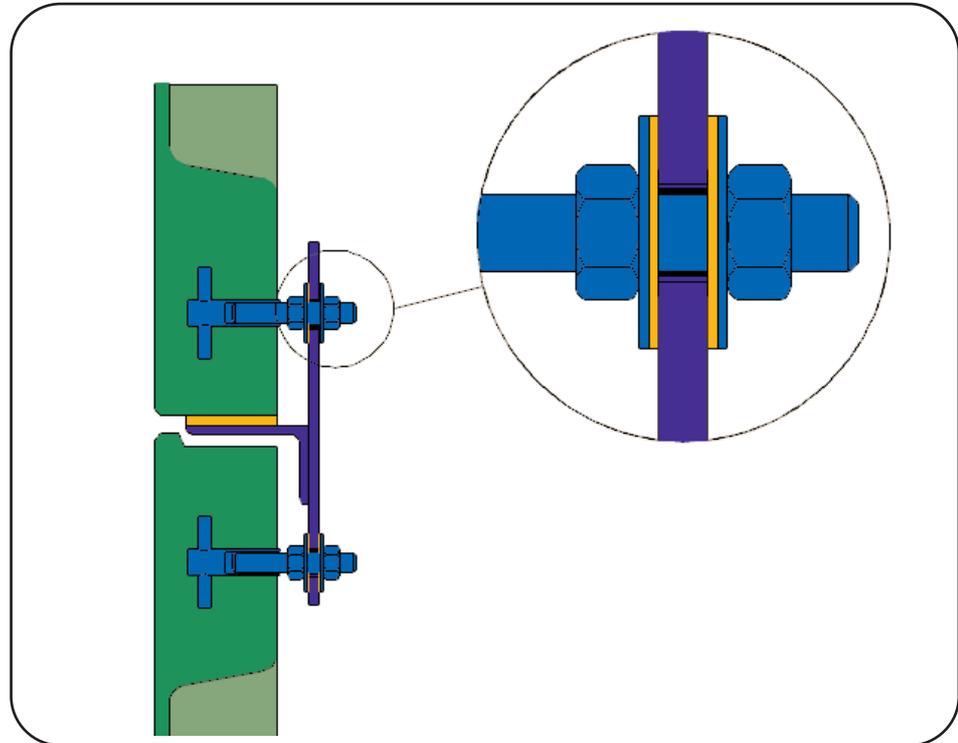


Figure 6.14 - Combined restraint fixings

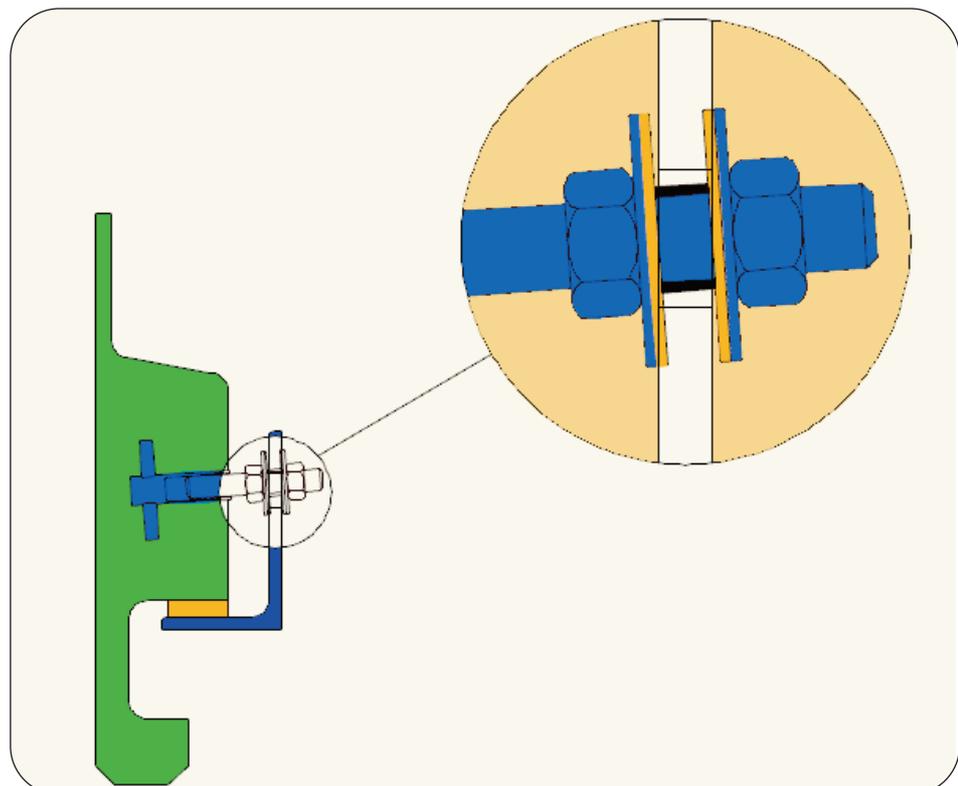


Figure 6.15 - Possible problems with cast-in fixings

Cast-in sockets being way out of tolerance are all too common (Figure 6.15). Care should be taken during manufacture to ensure that the positioning and alignment of cast-in sockets is as accurate as possible. In addition, oversized holes and/or other adjustments should be provided in the support components to avoid this becoming a problem on site.

6.4.3 GRC Stud Frame Cladding

When the stud frame is suspended over the freshly sprayed GRC facing, to facilitate bonding of the flex and gravity anchors onto the facing, the frame must be placed within tight tolerances to avoid problems with erection and jointing of the panels on site. Figure 6.16 highlights the critical dimensions of the stud frame panel with typical tolerances for manufacture of panels ≤ 3 metres long.

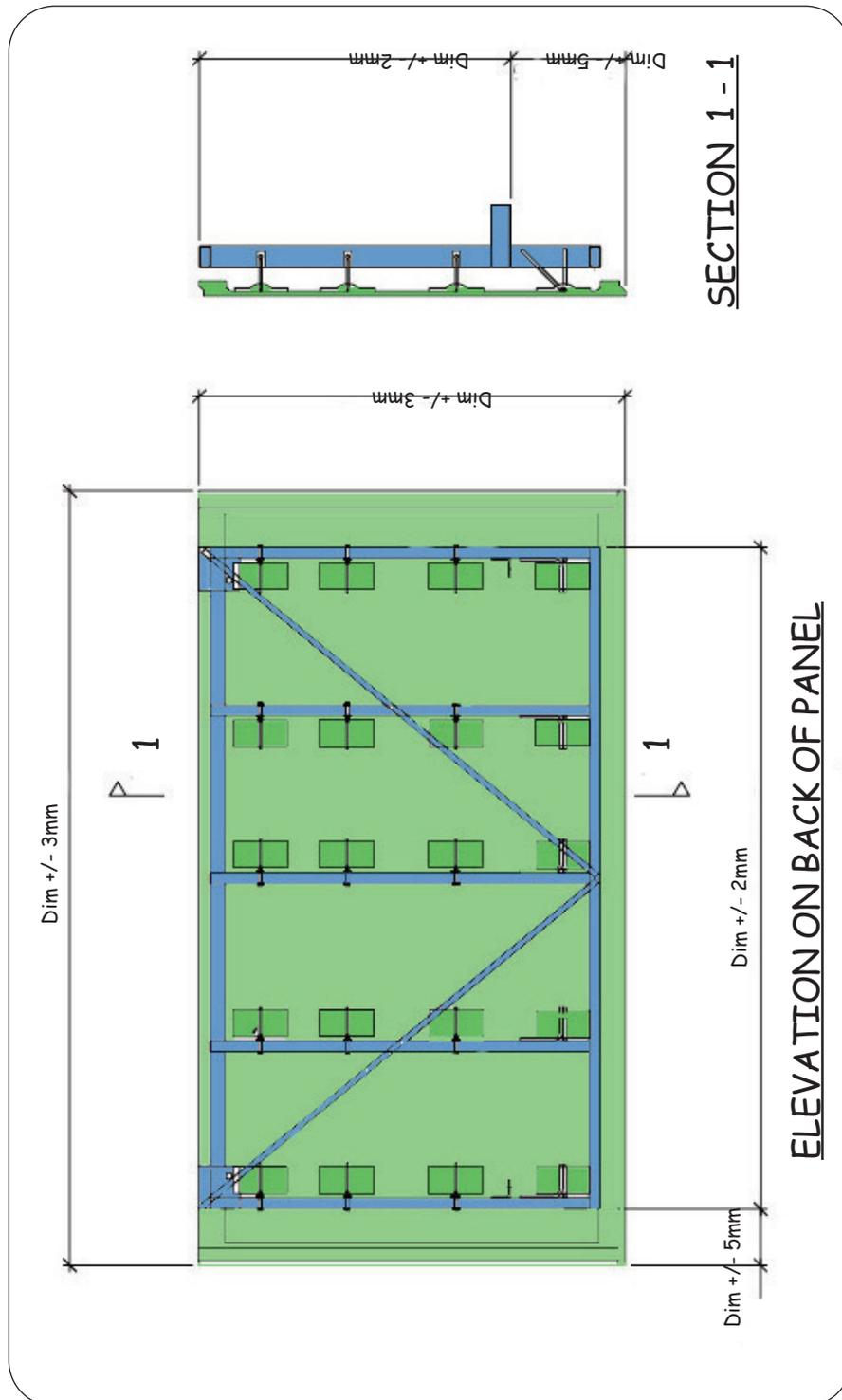


Figure 6.16 - Typical tolerances for Stud Frame Panel (≤ 3 metres long)

6.5 Interfacing with Other Constructions

The Programme of Works can have a significant effect on the way in which GRC panels are fixed to the structure. Ideally, the panels should be fixed early in the programme as this allows full access to the fixings. This usually means that the fixing work can be simpler and more cost effective than it would be otherwise. When the panels are fixed late in the programme, access to the fixings becomes more difficult. In the extreme, it may mean that panels can only be face fixed, albeit with some simple arrangement of seating cleats to support the self weight of the panels.

GRC cladding panels usually have to interface with other elements such as in-situ concrete, structural steelwork, windows, doorways, canopies and other architectural features. Each of these elements have allowable constructional tolerances that can combine to create problems for fixing GRC panels to be fixed later in the programme. The probability of a misfit occurring should be reduced to a minimum.

Tolerances and fits are the subjects of a Handbook produced by the Building Research Establishment (BRE) entitled "Graphical aids for manufacturers and builders". It is based on statistical data and removes the need for complex and repetitive calculations.

In addition, the construction industry has carried out an extensive survey of the accuracy achieved in building construction. The information from this survey has been collated and is contained in BS5606:1990 Accuracy in Building. More information about these publications can be found in BRE Digest 199 Getting Good Fit. The following two examples demonstrate how the information in BS5606:1990 is used to estimate the minimum and maximum joint sizes that are likely to occur.

Example 1 (Figure 6.17)

Target joint size 15mm

GRC panel size should have tolerance of $\pm 3\text{mm}$ ($< 3\text{m}$)

Space between columns should have tolerance of $\pm 18\text{mm}$ Table 1 T.1.1 (Fig 4) in BS5606:1990

Total deviation in size of joints = $(3^2 + 18^2)^{0.5} = 18\text{mm}$ (say)

Hence, maximum joint size = $15 + (18/2) = 24\text{mm}$

minimum joint size = $15 - (18/2) = 6\text{mm}$

So the joints must be capable of accommodating joint sizes of 6mm to 24mm to account for dimensional variations alone. Additional allowances should be made for the effects of shrinkage, temperature and moisture movements.

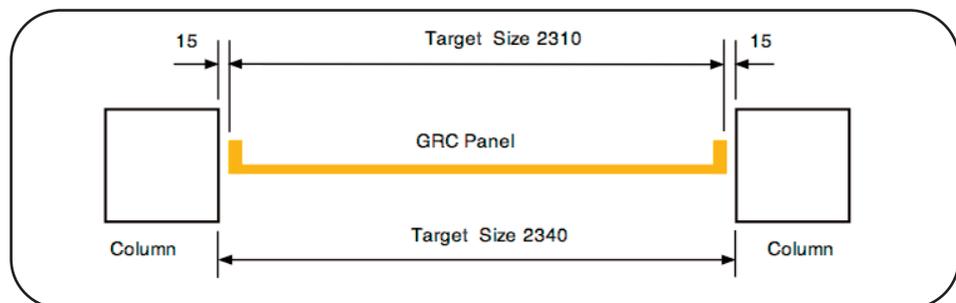


Figure 6.17 - Fixing GRC cladding panels between columns

A better solution is to avoid the problem altogether and use rebated columns, cover strips or lap joints as illustrated in Figure 6.18 (a) and (b).

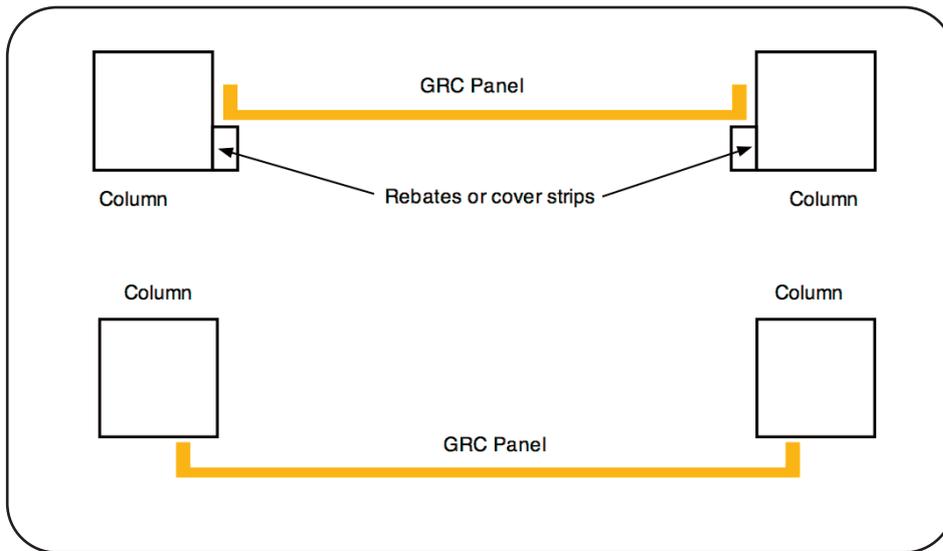


Figure 6.18 - Fixing GRC cladding panels between columns

Example 2 (Figure 6.19)

Target joint size = 12mm

GRC panel should have tolerance of ± 3 mm

Space between columns should have tolerance of ± 18 mm (BS5606: 1990)

Total deviation in size of joints = $(3^2 + 3^2 + 3^2 + 18^2)^{0.5} = 18$ mm (say)

Maximum joint size = $12 + (18/4) = 17$ mm

Minimum joint size = $12 - (18/4) = 8$ mm

This assumes that the end joints and internal joints have the same clearance allowances.

So joints must be capable of accommodating joint sizes of 8mm to 17mm to account for dimensional variations only. Additional allowances should be made for the effects of shrinkage, temperature and moisture movements.

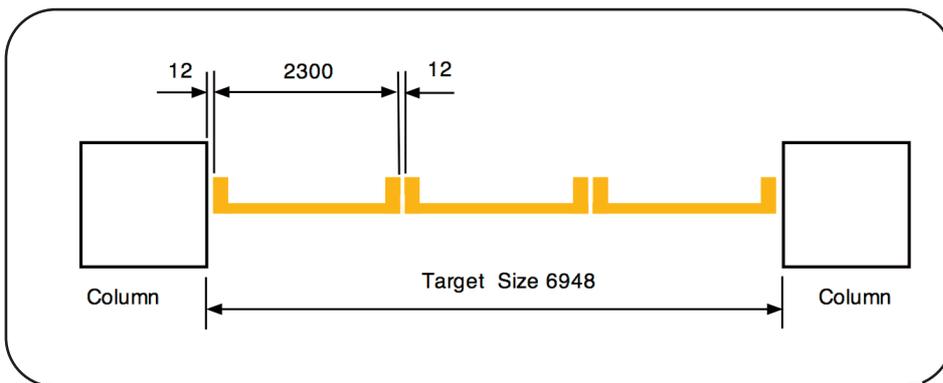


Figure 6.19 - Fixing numerous GRC cladding panels between columns

The estimation of thermal and moisture movements is covered in BRE Digest 228. Thermal expansion and contraction is estimated as follows:

Linear change in size = $\alpha L t$, where

α = coefficient of expansion, typically 7 to 12×10^{-6} per deg C

L = original length (mm)

t = change in temperature (deg C).

Applying this to the panel in Example 1 above, assuming a 30 deg rise in temperature,

$$\begin{aligned} \text{change in size} &= 12 \times 10^{-6} \times 2310 \times 30 \\ &= \underline{0.8\text{mm}} \end{aligned}$$

Moisture content in GRC consists of two components. These are irreversible shrinkage and reversible shrinkage. The latter depends on fluctuations in moisture content and is expressed as a percentage. It is typically in the region of 0.15% for GRC. Hence, referring again to the panel in Example 1, the change in size is $(0.15 \times 2310 / 100) = 4\text{mm}$ (say), ie 2mm at each end.

6.6 Use of Clamp Fixings

Clamps offer the GRC designer a wide variety of innovative solutions for making connections to structural steel support systems. The main cost saving are made from:

- Savings in installation times
- no necessity for specialised labour
- no requirements for special tools.

Clamp fixings are purpose made, malleable iron, hook bolt adapters that can securely grip the flanges of most steel sections. There is no need for drilling or welding on site. The total adjustability and versatility of clamps are illustrated in the following typical applications kindly provided by Lindapter (www.lindapter.com). Two animations have been included to give a clearer picture of how these clamping systems fit together. They are marked with the film clip icon similar to others in Part 2 of this Guide.

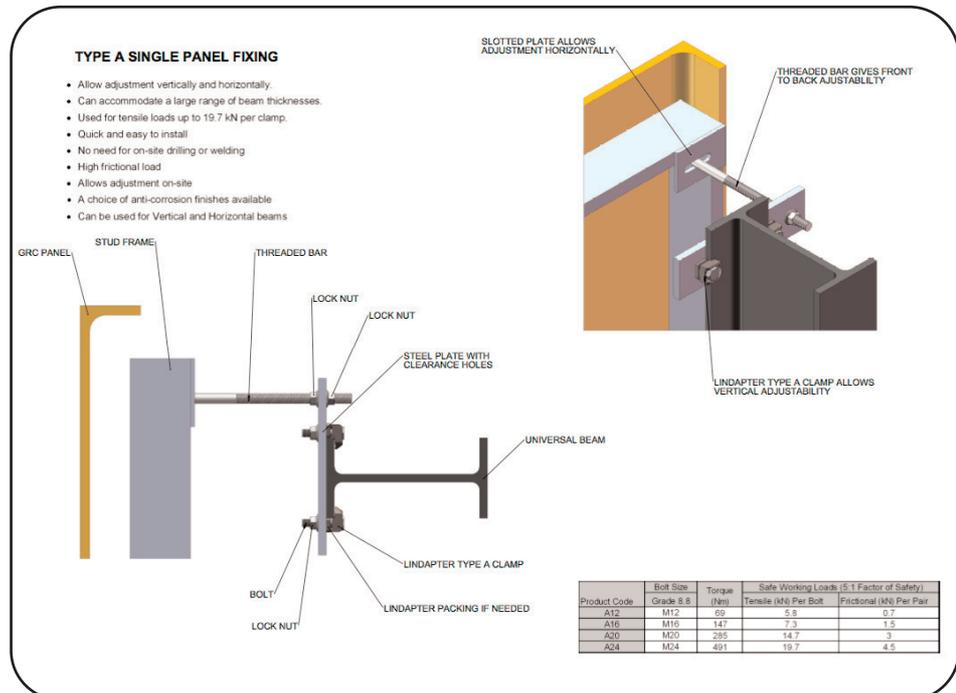


Figure 6.20 - Type A single panel fixing

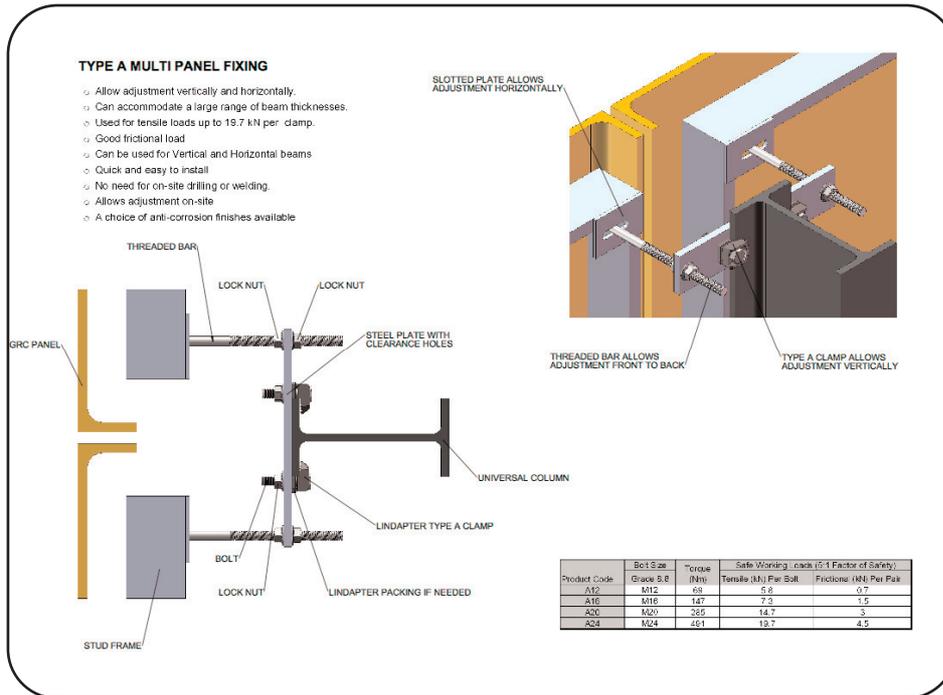


Figure 6.21 - Type A multi-panel fixing

Type A and Type LS are very similar in action but the latter takes slightly more tensile load but offers much more frictional resistance. When used in conjunction with slotted holes in stud frames, clamps provide a very high tolerance system of fixings requiring the minimum of work on site. The avoidance of site drilling/welding saves much time and effort and can result in significant savings in costs.

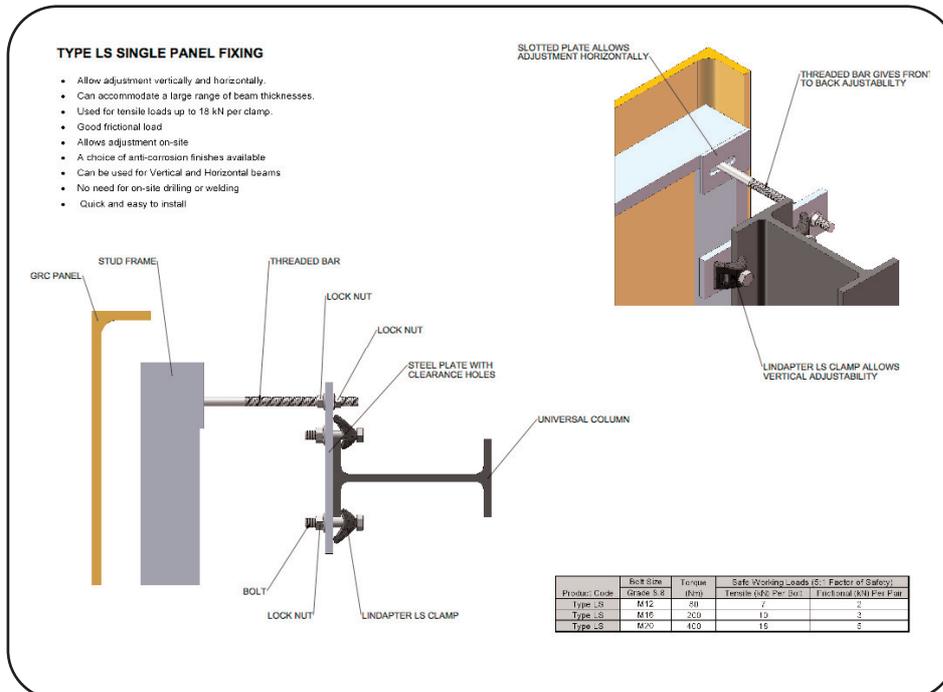


Figure 6.22 - Type LS single panel fixing

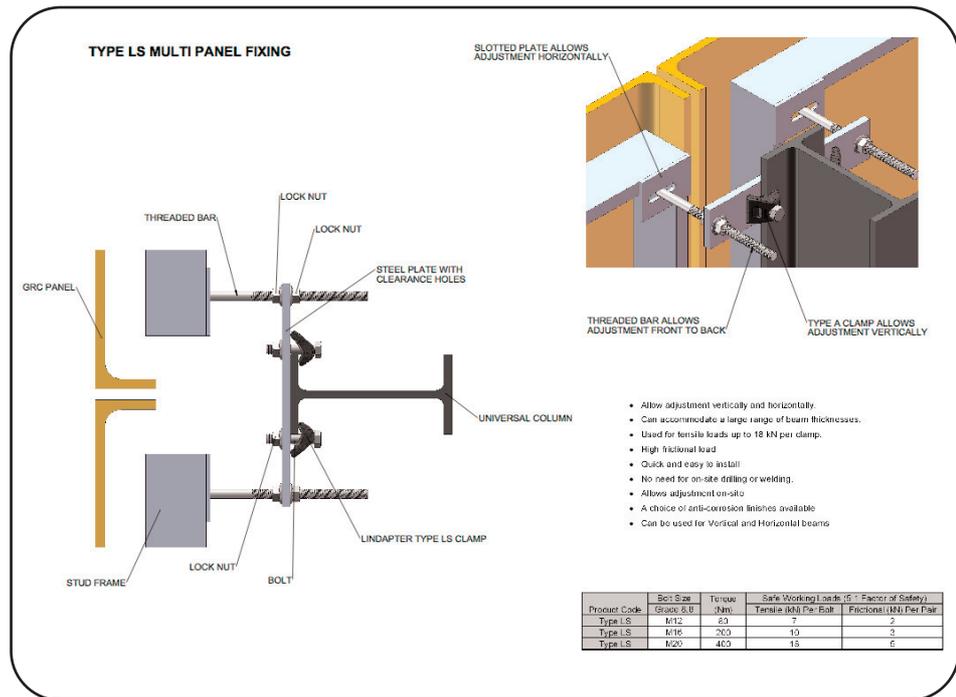


Figure 6.23 - Type LS multi panel fixing

Clamp Type LS allows an extremely large fixing tolerance in the vertical direction. Horizontal fixing tolerance is provided by slotted holes in one of the fixing plates as shown (Figure 6.23).

If a stronger anchorage is required, the LS type fixing can be strengthened by using unistrut insert in lieu of the plate (Figure 6.24).

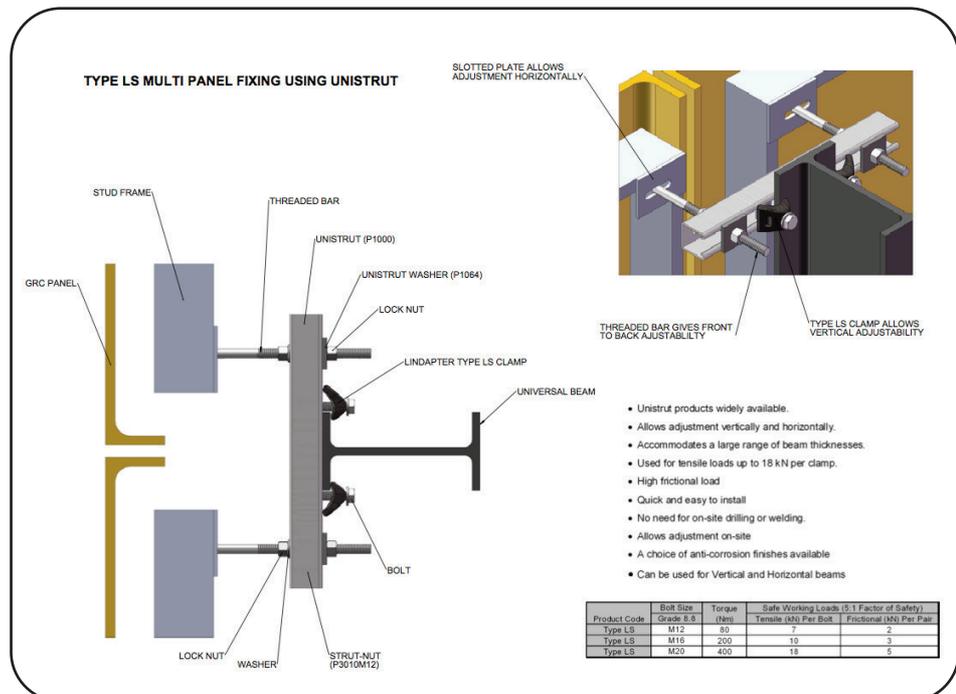


Figure 6.24 - Type LS multi panel fixing using Unistrut

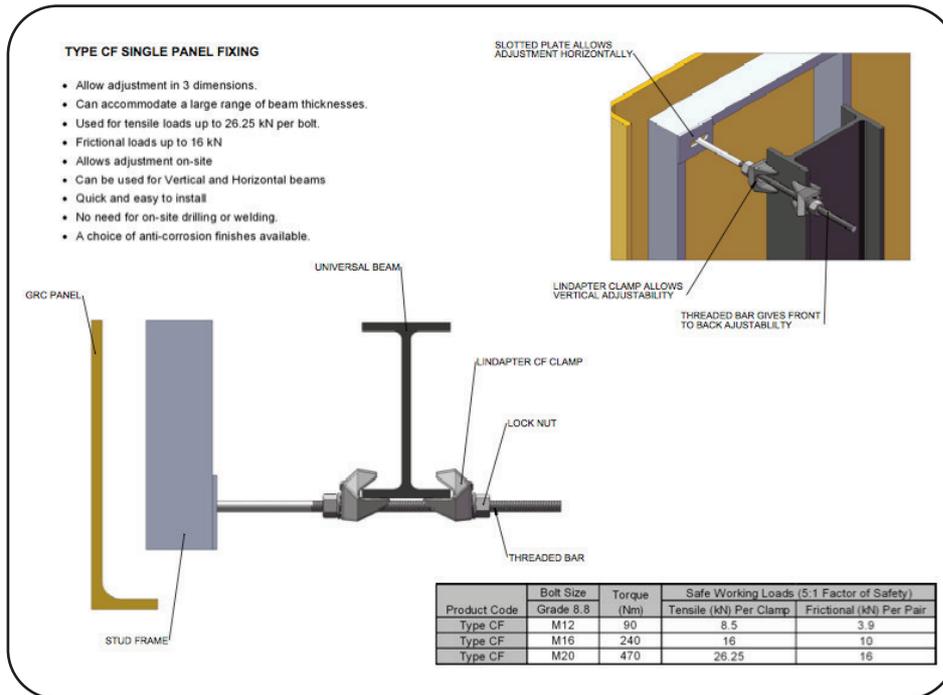


Figure 6.25 - Type CF single panel fixing

Clamp Type CF is particularly useful for anchoring GRC cladding panels to the flanges of beams and columns as shown in Figures 6.25 and 6.26. As with clamp Type A, slotted holes in the steelwork bonded to the GRC cladding are required to give full adjustability to this innovative type of fixing. The designer should check the effects of torsion, if any, on the supporting beams and/or columns.

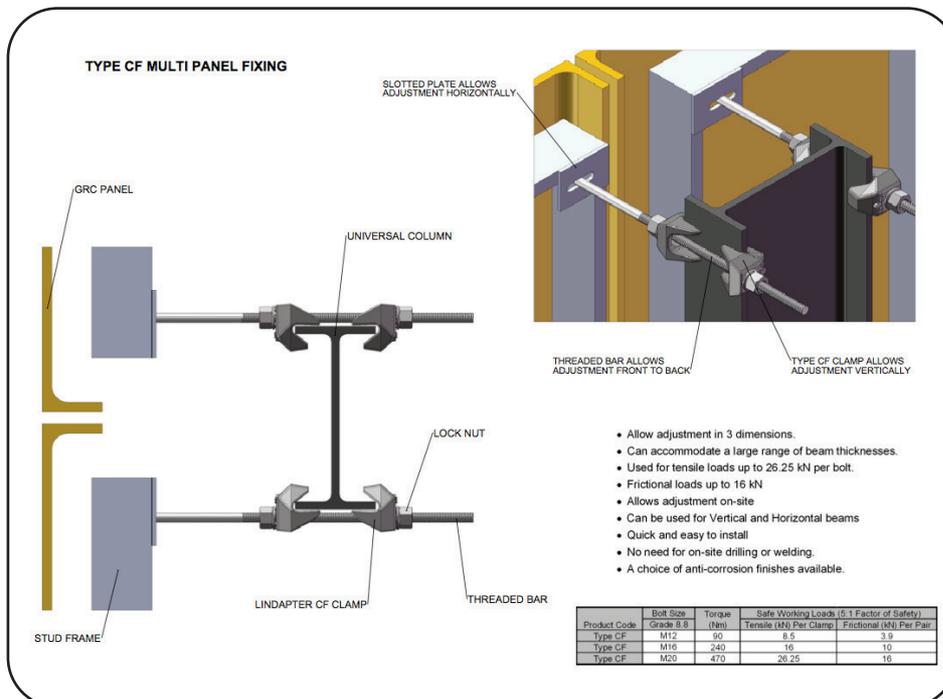


Figure 6.26 - Type CF multi panel fixing

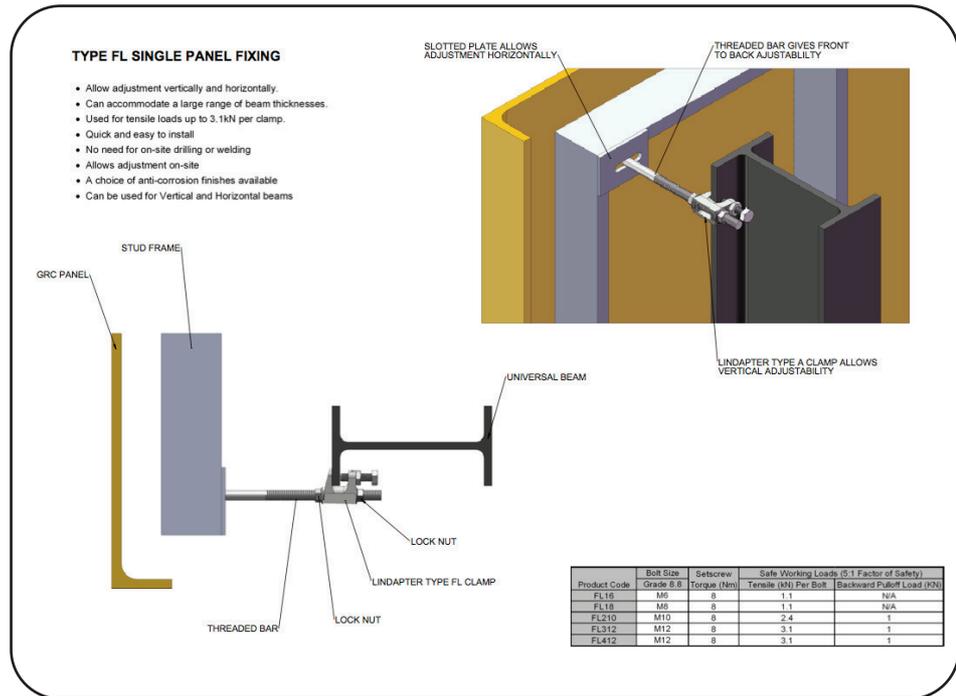


Figure 6.27 - Type FL single panel fixing

FL Type clamps facilitate a direct, albeit smaller, clamping action to the flanges of steel beams and columns (Figure 6.27). Consequently, they are only suitable for small to medium sized panels.

Hollo Bolts simplify connections to steel hollow sections. The required tolerances are achieved by the use of slotted holes aligned at right angles to one another, as indicated in Figure 6.28.

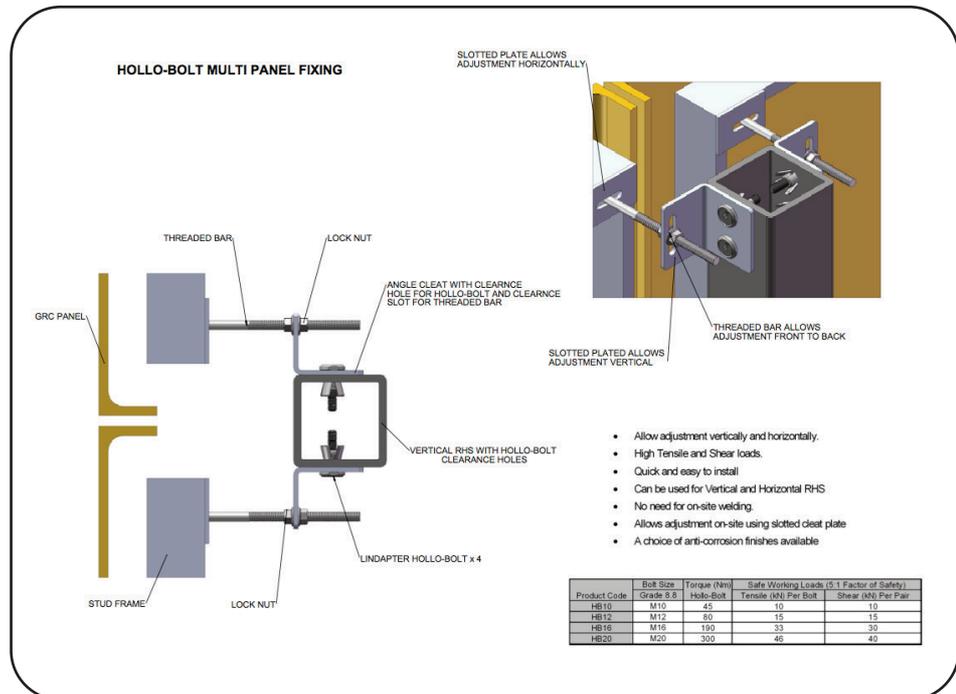


Figure 6.28 - Hollo-bolt multi panel fixing

6.6 Summary

First of all, it must be understood that zero tolerance is not achievable. The professional design team should determine and specify tolerances in accordance with current Standards and normal practice. In so doing, the team must appreciate that some of these specified tolerances may not be realised. Panels should not be rejected because they do not conform *exactly* with the specified tolerances. Means and ways of accepting them ought to be considered first. It is imperative that any proposed deviations in tolerances do not affect the long term integrity of the panels or become unacceptable with regard to aesthetic considerations.

Revisions to details and/or fixings are likely to cause delays and incur costs. Inevitably, some conflict(s) may result, but public health and safety are paramount and must not be compromised whatever the outcome.

FIXINGS FOR LIFTING & HANDLING

Separate fixings should be provided for lifting purposes to avoid possible damage to the permanent fixings. Lifting points should be placed symmetrically about the centre of gravity of the panel to ensure that it hangs as near vertical as possible when being lifted/handled (Figure 7.1).

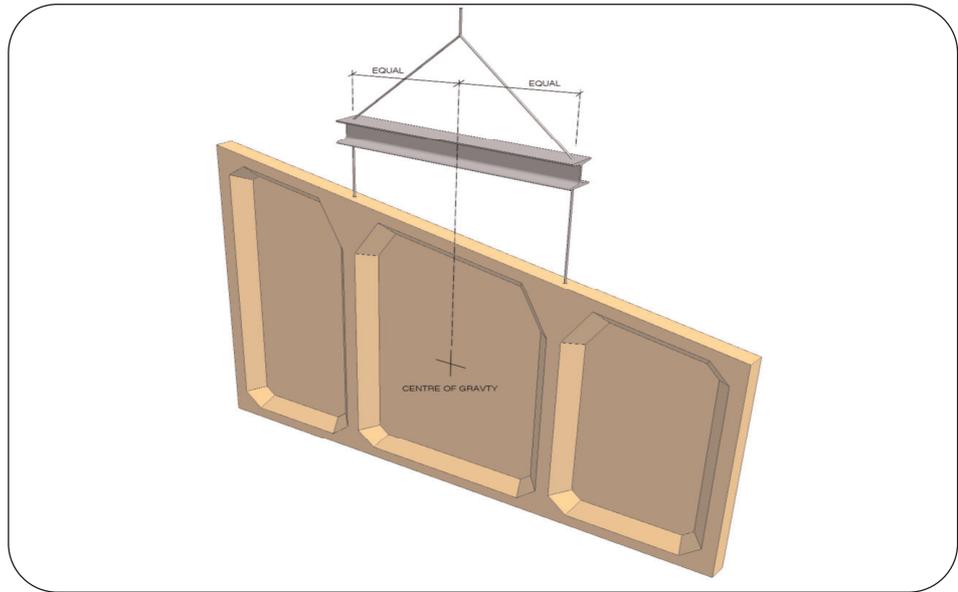


Figure 7.1 - Effective lifting through centre of gravity

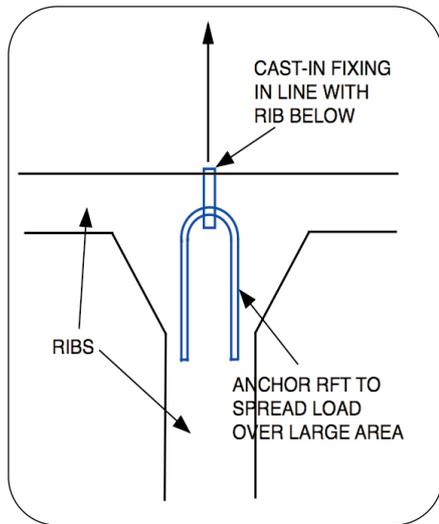


Figure 7.2 - Anchorage of cast-in fixing

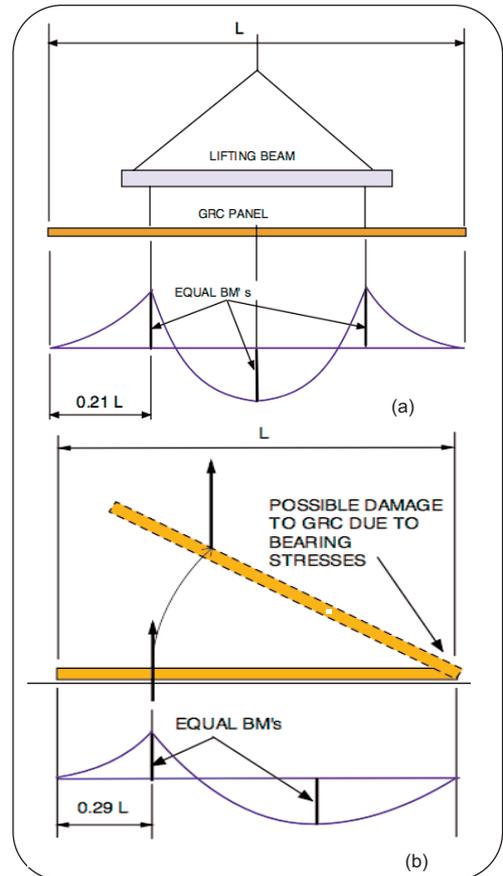


Figure 7.3 - Lifting arrangements

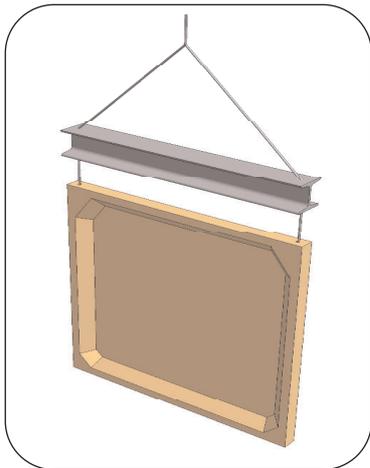


Figure 7.4 - Lifting points

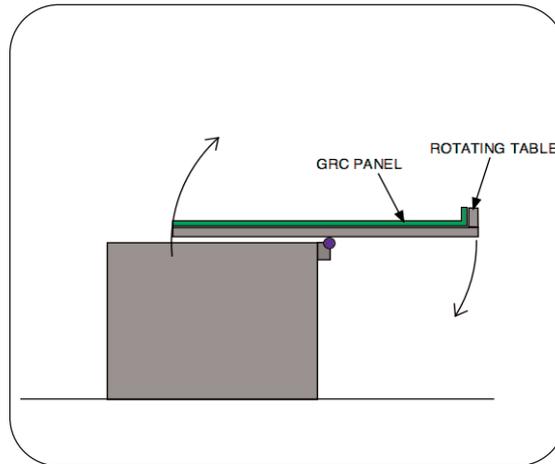


Figure 7.5 - Rotating table

Cast-in sockets offer the best means of providing lifting points and can be anchored more effectively by the use of anchor bars or pins (Figure 7.2).

Careful consideration should be given to the ways in which panels are to be demoulded, lifted and transported to site. Panels lying flat invariably have to be lifted and handled into the vertical at some time. Every effort should be made to minimise the bending stresses that are induced into the GRC during lifting operations (Figure 7.3). This is achieved by the careful positioning of lifting points (Figure 7.4), use of lifting frames, rotating tables (Figure 7.5) and avoidance of 'snatch' by the lifting equipment. If a panel weighs more than 40 to 45 kg it becomes difficult (and illegal) for two men to handle and so fixings should be provided to facilitate mechanical lifting.

Cast-in fixings used for lifting GRC panels are usually the same as those used for lifting precast concrete elements. Clearly, the performance of these fixings in GRC will not be the same. Consequently, the allowable load on them should be determined from controlled tests duplicating the loading conditions that they are likely to receive during lifting operations.

GRC stud frame panels are much easier to lift and manipulate. These panels should always be lifted by means of slings attached directly to the stud frames in order to avoid damage to the GRC facings.

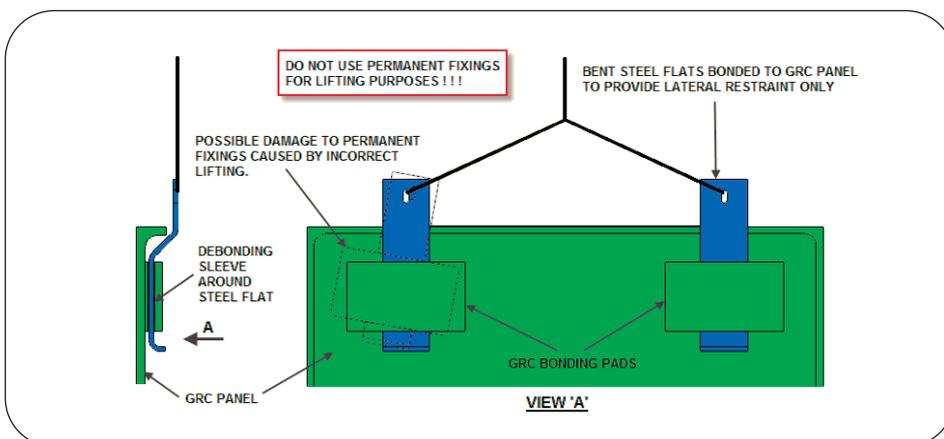


Figure 7.6 - Problems caused by incorrect lifting

Figure 7.6 illustrates a common misuse of permanent fixings. These are intended to be used for providing lateral restraint at the top of the panel. Unfortunately, this method of lifting, namely lifting with inclined slings, can cause latent damage to the bonding pad(s). Further movements of the panel, whilst in service, could cause failure of one or both of these pads with drastic consequences. Even vertical

lifting would cause the bent steel flat to slide upwards inside the debonding sleeve. One way to check this is by detailing the plate with a return along its bottom edge (Figure 7.6). The edge stiffening to the GRC panel may also help. Even so, this lifting practice is not safe and should be avoided at all costs.

NOTE

The use of mild steel fixings should be avoided except in very dry

Fixings are invariably located in damp environments. Most ferrous metals will corrode in these conditions and this can lead not only to unsightly staining of the building material but also to structural damage.

Corroded mild steel will laminate and expand to over four times its original thickness. This expansion would obviously have a devastating effect on GRC panels.

The two most common reasons for any metal fixing to not live up to expectations regarding corrosion resistance are:

- a. Incorrect assessment of the environment or exposure to unexpected conditions, e.g. unsuspected contamination by chloride ions.
- b. The way in which the materials are joined, stressed or treated may introduce conditions not envisaged in the initial assessment.

Pitting is a localised form of corrosion which can occur as a result of exposure to specific environments, most notably those containing chlorides. In most structural applications, the extent of pitting is likely to be superficial and the reduction in section thickness of a component is negligible. However, corrosion products can stain architectural features.

Durability is a measure of the fixings ability to resist deterioration. BS 7543 identifies a variety of agents that can cause deterioration of fixings. The most important stimulants of the corrosion of fixings are dissolved atmospheric/gaseous pollutants, moisture and temperature changes. Under dry conditions corrosion does not take place. However, moisture is present in most situations and so corrosion is always a potential risk.

8.1 Galvanised Fixings

NOTE

Welding of galvanised fixings should be avoided

Galvanising consists of immersing the article in a bath of molten zinc at a temperature in excess of 800 degC. Galvanising to BS 729 will greatly increase the life span of the fixing. All galvanised components have a finite life, directly proportional to the thickness of the zinc coating. Early corrosion can occur if this coating is damaged during handling. A number of buildings are now being designed with a minimum functional life of 60 years. It is doubtful if galvanising will provide the necessary protection. Welding of galvanised fixings on site should be avoided whenever possible.

8.2 Stainless Steel Fixings

In the UK, stainless steel is manufactured to the requirements of BS1449 : Part 2, BS 1501 : Part 3 and BS 970 : Part 1.

Stainless steel fixings are widely used for their durability and long life. They are generally very corrosion resistant and will perform satisfactorily in most environments. The corrosion resistance of a given grade of stainless steel depends upon its constituent elements and so each grade exhibits a slightly different response when exposed to the same corrosive environment. Consequently, care is needed to select the most appropriate grade of stainless steel for a given application. Generally, the higher the level of corrosion resistance required, the greater the cost of the material e.g. Grade 316 steel costs about a third more than Grade 304.

The main benefits of using stainless steel fixings are:

a) Low Maintenance Costs

Stainless steel components do not need painting or a protective coating. Stainless steel is, therefore, an obvious choice of material for fixings which are inaccessible (positioned out of sight, embedded in building material or underground) or those which would be difficult or expensive to replace.

b) Compliance with Client Requirements, Codes of Practice or Building Control.

Some codes of practice specifically recommend the use of stainless steel fixings in certain situations. Stainless steel, copper and copper-based alloys are the only recommended materials in BS 5628 : Part 3 : 1985 for fixings in masonry buildings over three storeys in height.

c) Total Life Cost

Greater importance is now being attached to the significance of total life-cycle costing because of the high costs of maintenance, shut-down, demolition and replacement of parts. Experience has shown that the benefits of a long life with zero maintenance and repair requirements more than compensate for the higher material cost of stainless steel.

Some stainless steel fixings are no more expensive than other metals of comparable durability.

d) Non-magnetic Properties

Non-magnetic fixings may be required in defence installations, medical buildings where magnetic scanners are used, runway calibration pads for the aircraft industry or transformer bases. Austenitic stainless steels are generally non-magnetic but may become slightly magnetic when cold-worked.

The use of frp or grp pultruded sections can provide the required strength and non-magnetic properties. Pultruded material is much lighter than steel and is easily drilled and cut on site. Bolts, nuts and washers can also be obtained in pultruded material but are relatively expensive. Stainless steel bolts, nuts and washers are generally used for bolting pultruded sections together.

e) Strength and Ductility

Cold and warm working can develop strengths in excess of 1000 N/mm² in austenitic stainless steel components. Stainless steels also exhibit good ductility and toughness, even after working.

f) Good High and Low Temperature Properties

Austenitic stainless steels retain high strength and good resistance to corrosion and oxidation at elevated temperatures and perform better than carbon steels. They are also one of the few steels to display good ductility and resistance to impact at very low temperatures.

g) Ease of Installation and Removal

The ease of installation, generally referred to as 'buildability', can be improved by restricting positive tolerances whilst allowing variations to be accommodated in the negative range.

Fixings must sometimes be capable of being released without damaging their surrounding components. However, rust and other corrosion may cause seizure and prevent fasteners from unscrewing. Providing the correct grade of stainless steel has been chosen, corrosion will not occur and fasteners can be removed without any difficulty.

h) Architectural Requirements e.g. Aesthetics

Although not normally a consideration for fixings, stainless steels can undergo a number of different surface treatments including mirror-polishing, abrading with different grit sizes, brushing, roll-texturing and colouring.

There are many types of stainless steel available but only austenitic stainless steel should be used for construction fixings. If there is a known pitting hazard, a molybdenum bearing stainless steel will be required to resist corrosion. Grade 304 (18/8) is used for most fixings and offers sufficient corrosion resistance for most building applications. Grade 316 (18/10) is a high grade stainless steel which is generally used for highly corrosive areas such as marine locations or highly polluted industrial environments.

8.3 Galvanic Corrosion

Galvanic corrosion may occur when two dissimilar metals are in electrical contact in a common electrolyte (e.g. rain, condensation etc). If a current flows between the two, the less noble metal (the anode) corrodes at a faster rate than it would otherwise have done had the the metals not been in contact. The rate of corrosion also depends on the relative areas of the metals in contact, the temperature and composition of the electrolyte. In particular, the larger the area of the cathode in relation to that of the anode, the greater the rate of attack. Adverse area ratios are likely to occur at interfaces between fixings and the main support structure. Carbon steel bolts in stainless steel members should be avoided because the ratio of the stainless steel to the carbon steel is large and the bolts will be subject to aggressive attack. Conversely, the rate of attack of a carbon steel member by a stainless steel bolt is much slower. It is usually helpful to draw on the experience of similar sites because dissimilar metals can often be safely coupled under conditions of occasional condensation or dampness with no adverse effects, especially when the conductivity of the electrolyte is low. The prediction of these effects is difficult because the corrosion rate is determined by a number of complex issues. The use of potential tables ignores the presence of surface oxide films and the effects of area ratios and different solution (electrolyte) chemistry. Uninformed use of these tables may produce erroneous results so they should be used with care and only for an initial assessment.

In practice, austenitic stainless steels usually form the cathode in a bimetallic couple and therefore do not suffer corrosion. An exception is the couple with copper which should generally be avoided except under benign conditions. Contact between austenitic stainless steels and zinc or aluminium may result in some additional corrosion of the latter two metals. This is unlikely to be structurally significant, but the resulting white/grey powder may be deemed unsightly by some. Bimetallic corrosion can be prevented by excluding water from the detail (e.g. by painting or taping over the assembled joint) or isolating the metals from one another (e.g. by painting the contact surfaces or the dissimilar metals). Isolation around bolted connections can be achieved by non-conductive plastic or rubber gaskets and nylon or teflon washers and bushes. The installation of these isolators is very time consuming and unless there is a high level of site supervision it is not surprising that some are left out or not properly installed. The general behaviour of metals in bimetallic contact in rural, urban, industrial and coastal environments is fully documented in *PD 6486, Commentary on corrosion at bimetallic contacts and its alleviation*.

Table 8.1 gives some general guidance as to metals which should not be placed in direct contact with one another.

NOTE
Examples of the use of isolating sleeves and washers are given in Section 6.

Table 8.1

	Aluminium	Aluminium Bronze	Cast Iron	Copper	Phosphor Bronze	Lead	Stainless Steel	Steel	Tin	Zinc
Aluminium										
Aluminium Bronze										
Cast Iron										
Copper										
Phosphor Bronze										
Lead										
Stainless Steel										
Steel										
Tin										
Zinc										

May be used together in ALL conditions
 MUST NOT be used in contact
 May be used together in DRY conditions

8.4 Crevice Corrosion of Steel

Crevice corrosion is a localised form of attack which is initiated by the extremely low availability of oxygen in a crevice. It is only likely to be a problem in stagnant solutions where a build-up of chlorides can occur. Crevices typically occur between nuts and washers, around the thread of a screw or around the shank of a bolt. Crevices can also occur in welds which fail to penetrate, under deposits on the steel surface and under iron particles embedded in the surface of the steel.

8.5 Stress Corrosion Cracking of Steel

The development of stress corrosion cracking requires the simultaneous presence of tensile stresses and specific environmental factors unlikely to be encountered in normal building atmospheres. The stresses do not have to be very high in relation to the proof stress of the material and may be due to loading, residual effects from manufacturing processes (such as welding, bending) or wedging action of corrosive products growing in a crack.

8.6 Fibreglass Pultrusions

The use of pultruded composites to form support structures for GRC cladding systems is a relatively new application. These materials have many advantages that are not all readily obvious until all their mechanical properties are studied and appreciated in the context of supporting lightweight GRC elements. In this context, the relevant physical advantages of pultruded composites are as follows:

(a) High strength

On a weight for weight basis, pultruded composites are stronger than steel. The enhancement of many of their mechanical properties is achievable by varying the type and orientation of the reinforcements. However, their flexural modulus generally remains in the range of 13 to 20 N/mm². This is an important property when considering the effects of deflections in design.

(b) Lightweight

Weighing up to 80% less than steel and 30% less than aluminium, pultruded profiles are able to enhance the lightweight characteristics of GRC cladding systems. This is also a very important property when considering limitations imposed by Health & Safety Regulations on lifting by hand.

(c) Resistant to corrosion

Pultruded profiles have a good corrosion resistance when subjected to a wide variety of corrosive chemicals and environments. Most profiles have a synthetic coating which provides a resin rich layer that gives the material its high corrosion resistance.

(d) Maintenance free

This property is very important when faced with the dichotomy where galvanised steel fixings are not acceptable, for instance, in coastal situations and where the cost of stainless steel fixings is prohibitive. Pultruded profiles are marginally more expensive than steel galvanised ones, but gain in advantage when the cost advantages of being relatively easier to drill and cut on site are taken into account.

(e) Fire retardent properties

Continuous exposure to temperatures up to 65 deg C is well within the capacity of most pultruded profiles. Custom designed profiles can withstand higher temperatures. Pultruded profiles are not readily combustible. Combinations of resin matrix and fibre reinforcement can be formulated to meet extremely rigorous fire safety standards. Some types offer superior fire performance with exceptionally low smoke and toxicity levels, whilst phenolic resins will maintain some structural integrity at very high temperatures.

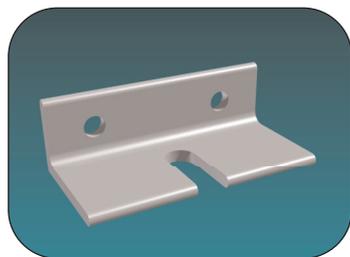


Figure 8.1 - Cutting/drilling of pultruded profiles.

(f) Site Modifications

Pultruded profiles are easy to drill and cut on site using diamond tipped drills and saws. This property can be used to great advantage by leaving some drilling and cutting to be done on site thereby overcoming difficulties posed by tight tolerances.

Joints between pultruded profiles are usually formed by gluing and bolting them together using an approved glue and stainless steel nuts, bolts and washers. It is essential that all surfaces exposed by drilling and cutting are sealed; the glue used for forming the joints can usually be used for this purpose.

(g) Disadvantages

An important disadvantage with pultruded profiles, manufactured using polyester resins, is that if they come into long term, direct contact with cementitious products, eg concrete, including glass reinforced concrete products, they can suffer degradation from a hydraulic attack known as 'hydrolysis'. This is accelerated if the contact occurs in wet and warm situations. It is not advisable, therefore, to cast pultruded profiles manufactured with polyester resin into concrete foundations, slabs etc. The problem is overcome by specifying a different, but more expensive, resin to be used in the manufacture of the pultruded profiles.

Designers considering the use of common pultruded sections must also appreciate that they are anisotropic. Clearly, they are strongest in the direction of the pultrusion and weakest in a direction at right angles to the pultrusion. In fact, the ratio of weakest/strongest strengths can be less than 0.25. More expensive types of pultrusions can overcome this problem to a certain extent, but the use of these in this context would most likely be prohibitive in cost. Finally, designers should understand that different manufacturer's pultruded profiles are unlikely to have identical properties and should, therefore, use the manufacturer's specific data when designing them.

FACTORS AFFECTING THE COST OF DESIGN/DETAILING

Each GRC cladding project will present its own inherent difficulties. The GRC designer must first decide which type of panel is likely to be the most simple and cost effective to use. Clearly, on a very large project this might not be as easy as it sounds. Indeed, it may be necessary to utilize more than one type of panel e.g. ribbed panels and stud frame construction.

The main objective on each and every cladding project must be to balance the total costs, including professional fees, against aesthetic issues, simplicity in manufacture, ease of transportation/handling and fixing on site. Understandably, the client will want to minimize these costs. It is important, therefore, for the designer to attend meetings with the Architect, manufacturer, fixing team and organisations responsible for fixing interfacing elements, such as glazing and doorways, as soon as possible before the start of the proposed Programme of Works. Whilst it is difficult to generalize, the following factors, at least, should be discussed to arrive at a suitable choice of GRC cladding and fixings.

- Location of site (coastal, rural exposure etc) - *it may be that only expensive stainless steel fixings are suitable.*
- Total area of cladding - *this is useful for checking the costs against normal rates.*
- Repetition and complexity of cladding - *the more repetition of simple panels will lower the cost substantially.*
- Which type of panel is suitable for the construction - *a mix of panel types might be necessary.*
- Site access - *restrictions can have a significant effect on costs.*
- Possible conflicts and disagreements with other specialists - *these are avoided by having meetings of all concerned before the works are carried out.*
- Temporary works obstructions - *such as scaffolding, lifts etc.*
- Programme of Works - *all too often the fixing of GRC cladding panels is left until late in the Programme. Arguments for this relate mostly to the possible damage to the panels by other trades during construction. However, the timing of fixing the panels is crucial. If it is left to the last minute, only face fixing the panels may be possible. The expected tolerances for fixing may also be severely compromised; this can lead to arguments and claims. Another issue relates to the removal of scaffolding; sometimes, the contractor may insist on cladding being fixed from top down as scaffold is removed. This can complicate the method of fixing and result in increased costs.*
- Number of different types of panels - *the smaller the better. Obviously, the cost of different formworks, together with the associated higher design costs, may rule out the use of GRC cladding altogether. Standardisation and repetition of the panels is the best way to alleviate this problem.*

- Weather conditions - inclement weather is obviously not good for fixing panels, particularly at great heights. Sometimes it is possible to plan the work with reference to long range weather forecasts and/or seasons of the year.
- The level of Professional Indemnity Insurance and cross-party contracts specified in the Contract Documents are often unreasonably higher than necessary - the cost of premiums has to be paid for somehow. Understandably, this reflects in the fees proposed by the designers.
- Estimated cost of cladding + fixings, produced by the manufacturer - this together with the area of cladding are extremely useful to the designer in preparing his proposed fees.



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