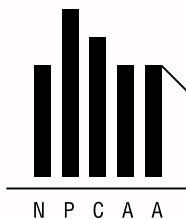


A RECOMMENDED PRACTICE

**Design, Manufacture and Installation
of
Glass Reinforced Concrete (GRC)**



Provided by the
**GRC Industry Group of
National Precast Concrete Association Australia**

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2 INTRODUCTION

Glass Reinforced Concrete (GRC) is a composite material consisting of a portland cement and sand mortar, reinforced with alkali-resistant glass fibres. The GRC may contain additional filler materials and admixtures. Fibre content varies by weight depending on product application and production method employed. The final properties of GRC depend on a wide range of variables such as mix materials and formulation, manufacture, fibre product type, length and orientation and admixtures used. A GRC material may be tailored to meet the particular requirements of a specific application. The information given in this publication refers to GRC incorporating AR glass fibre, made by the spray and vibration cast processes. The materials and manufacturing techniques discussed have been widely used for a number of years and their properties and characteristics studied extensively.

GRC is a composite material which combines the high compressive strength properties of cement mortars with significantly increased impact, flexural and tensile strength imparted by the fibre reinforcement. GRC does not contain asbestos, has good chemical resistance and will not rot or corrode. GRC is made of inorganic materials and will not burn, has negligible smoke emission and offers good fire resistance. In some circumstances, GRC is manufactured using polymer materials which may vary the fire performance properties. Products of relatively thin cross section can be made, giving a low component weight which may allow savings in handling, storage, transportation, installation and in the supporting building frame.

There are two main methods of manufacture:

- Spraying of the fibre and slurry onto a mould, by manual or mechanical means.
- Premixing the fibre and slurry and then casting into a mould, usually utilising vibration.

Typical products made using the spray process include architectural cladding panels, agricultural components, tanks, facade elements, ducting and formwork.

Products made using the premix process are sunscreens, planters, electrical transformer housings, junction boxes and drainage components.

The potential for the use of glass reinforced concrete systems was recognised during the early development work on glass fibre reinforced plastics carried out in the 1940s. This early experience indicated that portland cement composites made with unprotected "E" glass (conventional glass fibre reinforcement as used in reinforced plastics) were subject to alkaline attack. Because of this, a special glass fibre product was developed. Following the successful development of AR (alkali resistant) glass fibres in the late 1960s, test programmes were undertaken to determine the properties of portland cement and AR glass fibre composites.

Prior to the mid 1980s, people had tended to think of GRC as a material with one unique set of engineering properties. This is far from true. Besides vibration cast and spray-up manufacturing methods, different matrix formulations including different forms of polymer addition or different cements combine to form characteristic mechanical properties. These properties will vary depending on the environmental conditions to which the material is subjected.

GRC is also used for furniture, cladding and as permanent formwork. The material has always been deemed "quasi-structural", meaning it can be structural but within a limited scope of consequence of failure. The consequence of failure of GRC must not be such that it could cause progressive collapse. It can be used in isolation structurally in a temporary application (eg formwork). It can be used structurally in conjunction with other materials in a long-term application as long as failure of the GRC would not lead to collapse without warning.

When used purely in compression, GRC can be treated in the same way as high strength unreinforced concrete.

IMPORTANT:

This publication is intended for use by professional persons competent to evaluate the significance and limitations of this document, and able to accept responsibility for the application of the material contained herein. Projects may require more-specific evaluation and engineering judgement.

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- Huntsman Composites www.huntsman.com
- Nippon Electric Glass www.neg.co.jp/eng/

3 DEFINITIONS

Admixture

A material other than cement, fine and (occasionally) coarse aggregate, glass fibre and water, added to modify either the plastic or hardened state properties of the matrix.

Air Permeability

The rate at which air flows through a material, commonly expressed in metric perms.

Alkali Resistant (AR) Glass Fibre

Fibre made from glass having a high zirconia content (minimum 16%) formulated to improve resistance to attack by aqueous alkaline solutions.

Ambient temperature

The temperature of the surrounding air, during manufacture, storage or in service.

Anchor

Device for the attachment of the skin to the panel framing system; includes flex, gravity and seismic anchors.

Artificial Aging

A condition to which test specimens are subjected in order to simulate their exposure to natural weathering; usually the intent is to accelerate any aging effects.

Attachments

Both anchors and connections.

Backing

The GRC mix deposited into the mould after the face mix, veneer or mist coat has been placed and consolidated.

Bondbreaker

A substance placed on a material to prevent it from bonding to the GRC, eg between a face material such as natural stone and the GRC backing, to allow differential movement of the materials.

Bonding Agents

A substance used to improve the bond between an existing piece of GRC and a subsequent application of GRC, such as a patch.

Bonding Pad

A supplemental section of GRC material which covers the foot of the flex, gravity or seismic anchor.

Boss

A localised thickening of the backing mix into which an insert can be embedded

Carbonation

Reaction between carbon dioxide and a hydroxide or oxide to form a carbonate, especially in cement paste, mortar, or the reaction with calcium compounds to produce calcium carbonate.

Chopped Glass

Short lengths of multi-filament glass fibre strands, chopped from roving in the spray-up process.

Cladding panel

A lightweight non-structural GRC prefabricated wall panel produced by the spray-up or premix process for use as an exterior wall panel. When attached to a stud frame, the panel may become a structural member.

Clearance

Interface space (distance) between two items.

Compaction

The process whereby the volume of the face mix or GRC backing is reduced to the minimum practical volume by the reduction of voids. Usually by vibration, tamping, rolling or some combination of these.

Composite

A material obtained by blending two or more different materials; but so interconnected that the combined components act together as a single member and respond to load as a unit.

Connection (Connector)

Device for the attachment of GRC units to each other or to the building structure.

Coupon

Specimen for testing.

Crazing

A network of very fine surface cracks in random directions often providing a map-like appearance. Often, this pattern is not readily visible, only becoming so when highlighted by atmospheric dirt.

Curing

The provision of moisture and adequate temperature for a defined period to allow hydration to occur and so develop both strength, hardness, impermeability and to limit shrinkage.

Where the curing temperature remains in the normal environmental range, generally between 15 and 40°C, the term *normal curing* is used; where the curing temperature is increased to a higher range, generally between

40 and 50°C, the term *accelerated curing* is used.

Dew point

Temperature at which the atmosphere becomes saturated with water vapour due to cooling.

Draft/Draw or Taper

The slope of the mould surface in relation to the direction in which the GRC element is withdrawn from the mould to facilitate stripping.

Dry Density

The weight per unit volume of an oven dry specimen; commonly expressed in kg/m^3 . In the range of 1900–2000 kg/m^3 for normal or standard GRC.

Ductile Appearing or Pseudo-Ductile

Large permanent deformation without apparent rupture but in fact having multiple cracking; unaged GRC has these characteristics.

Engineer

A person qualified for Corporate Membership of the Institution of Engineers Australia or equivalent and competent to practice in structural design.

E* (Early)

One of two general ages in the life of GRC components. Often but not always associated with 28 days. Specifically, an age prior to the time-dependent property changes.

E-Glass Fibre

Borosilicate fibres widely used for the reinforcement of plastics. Not recommended for use with portland cement.

Efflorescence

A thin, hard, generally white-ish film at the GRC surface. Attributed to free soluble calcium hydroxide forming during the hydration of the cement, migrating to the surface where it reacts with carbon dioxide in the atmosphere to form an insoluble calcium carbonate. Normally removed by washing with acid, diluted with water.

F (Flexural)

Flexural strength at either yield (Y) or ultimate (U). The apparent maximum stress when GRC is subjected to flexural loading ($M_c/1$). This is the most commonly used measure of strength.

Face mix

A mix incorporating aggregate, but having no glass fibre reinforcement. Used to achieve a specific architectural finish.

Felt

The mix of mortar and AR glass fibres when in a plastic state.

Fibre

An individual glass filament with an average diameter of 13 to 20 microns and not less than 9 microns in diameter.

Fibre Content

The ratio, usually expressed as a percentage, of the glass fibre to the total mix; can be by weight or by volume, preferably the former.

Fixings

See Hardware.

Flex Anchor

Rod or bar that connects the GRC skin to the panel frame.

Gap-graded Mix

A face mix with one, or a range of normal aggregate sizes eliminated, and/or with a heavier concentration of certain aggregate sizes over and above standard gradation limits; it is used to obtain a specific exposed aggregate finish.

GRC

Glass Reinforced Cement or Concrete. The terms Glass Reinforced Cement and Glass Fibre Reinforced Concrete are treated as being synonymous.

Gravity Anchor

Rods, bars or plates that transfer the gravity load of the panel to the stud frame.

Hardware

A collective term applied to items used in connecting GRC units or attaching or accommodating adjacent materials or equipment.

Contractor's hardware – Items to be placed on or in the structure in order to receive the GRC units, eg anchor bolts, angles or plates with suitable anchors.

Manufacturer's hardware – Items to be part of the GRC units themselves, either for connections and GRC erector's work.

Special Erection hardware – All loose hardware items necessary for the installation of the GRC units.

Insert

A connecting or handling device cast into GRC units. Inserts are machine or coil-threaded to receive a bolt or slotted to receive a bolt head, nut, strap anchor or threaded rod.

LOP

Limit of proportionality of a standard flexural test specimen. It is a measure of the flexural strength at the elastic limit (yield strength).

Matrix

The cement paste into which various amounts of aggregate particles and glass fibres are incorporated.

Micro-cracking

See Crazing.

Mist Coat

A thin coat of cement/sand slurry of a similar composition as the GRC backing mix but without glass fibre, applied to the surface of the mould to give a smooth, even surface and hide the glass fibres. It is just thick enough to cover the mould surfaces.

3.0

Moisture Migration

The movement of moisture through the skin.

Moisture-induced Movement

Volume change of the skin due to changes in moisture content. Volume change may be contraction or expansion.

MOR

Modulus of rupture (flexural). A measure of flexural strength at failure of a standard flexural test specimen.

MOR_k

Characteristic Modulus of Rupture. The value which 95% of all mean strengths of the individual test boards should exceed.

Panel

The entire prefabricated GRC assembly

P-GRC

Polymer (modified) GRC or GFRC with added polymer; where the polymer solids content is greater than 5% by weight of cement.

Plastic Cracking

Short cracks often varying in width along their length, which may occur in the surface of fresh GRC soon after it is placed and while it is still plastic; some probable causes of plastic cracking are rapid moisture loss, high water content, low sand content, or poor grading and poor compaction. May be overcome with further compaction and working.

Polymer

As used in this Recommended Practice, an emulsion of an alkali resistant synthetic thermoplastic in water obtained by polymerisation and used to enhance or modify the properties of the matrix.

Premix

A process of mixing cement, sand, chopped AR glass fibre and water together into a reinforced mortar and subsequently spraying or casting with vibration, press-moulding, extruding or slipforming the mortar into a product.

Return

A projection of like cross section to the face which is 90° to, or splayed from the main face or plane of view, usually at the edges of the panel projecting back from the face.

Reveal

Groove in a panel face generally used to create a desired architectural effect.

Rib

A stiffening member backing the skin, or a projection from the panel face.

Roving

A group of glass fibre strands gathered together and wound to a rope-like appearance. Usually 20 to 50 strands form a roving.

Sandwich Panel

A prefabricated panel which is a layered composite formed by attaching an inner and outer skin to a core material.

Scrim

A non-woven cloth having open construction (windows) of over 40 mm², manufactured using AR glass fibre strands. It is laid up by hand to reinforce an area of the GRC backing.

Seismic Anchor

Rods, bars or plates that transfer the earthquake loadings from the GRC cladding to the frame.

Sizing

Coating materials applied to the glass fibres during manufacture to facilitate and/or improve the processing and performance of the fibre. It holds the filaments together to form a strand and controls the dispersion of the strand into filaments during spray-up and compaction.

Skin

The thin exterior section of a panel, including the face mix/veneer finish and GRC backing mix but exclusive of backing ribs, bosses, stud frame, etc.

Skin Segment

The discrete sections of skin within a panel separated by control joints.

Slump Test

A simple plant test for determining the apparent viscosity of the cement slurry or mortar.

Slurry

A mixture of water, portland cement, sand, and other approved additions or admixtures in suspension.

Spray-up Process

The simultaneous depositing of glass fibres and slurry by spraying onto a mould followed by appropriate compaction.

Strand

A number of individual continuous filaments bound together by sizing. Typical AR glass fibre strands contain between 50 and 200 filaments.

Stripping

The process of removing a GRC element from the mould into which it was sprayed or cast.

Stud Frame

Factory attached steel frame of cold-formed studs or structural shapes used to support and stiffen the panel and to provide a means for connecting the panel skin to the supporting structure.

Superplasticiser

A high-range water-reducing (HRWR) admixture producing a cement mortar or slurry of significantly higher slump without the use of additional water.

T* (Tensile)

Tensile strength at either yield (TY) or ultimate (TU).
A uniform stress as contrasted to flexural stress.

Test Board

A test sample produced by spraying up simultaneously with and alongside the production panel from which coupons are cut for testing.

Tex (Roving or Strand)

The weight in grams of a 1000-m length of roving or strand.

Thermal Movement

Dimensional change of the skin due to temperature change of the skin; such change may occur as contraction or expansion.

Tolerance

Specified permissible variation from stated requirements such as dimensions and strength.

Trowel Surface

The surface of a panel (not in contact with the form or mould during manufacture) made by smoothing with a trowel or roller.

Vapour Permeance

The rate of water vapour transmission per unit of vapour pressure differential; commonly expressed in perms.

Vibration Cast

GRC manufacturing technique utilising vibration to achieve compaction.

Volume Change

An increase or decrease in volume of the skin, resulting largely from linear changes of the GRC skin. It includes initial (irreversible) drying shrinkage and subsequent moisture and thermal movement.

Wythe

Each continuous vertical section of a wall.

Wythe Equivalent Thickness

The thickness of a solid flat wythe having the same volume as the wythe in question. For a wythe having a non-uniform cross section throughout its length, the equivalent thickness is equal to the cross-sectional area divided by the length of the cross section.

Y (Yield)

Yield point or strength; point on a stress/strain curve at which strain ceases to be proportional to stress.

4 MATERIALS

4.1 ALKALI-RESISTANT (AR) GLASS FIBRE

AR Glass Fibre is an alkali-resistant glass fibre with high durability when used in cement-based products.

Specifiers are reminded that *E-Glass* fibres are NOT alkali-resistant and should NOT be used in association with cementitious binders.

Some typical properties of AR Fibre are as follows:

Single filament tensile strength	3.5 GN/m ²
Strand tensile strength	1.4 to 1.7 GN/m ²
Young's Modulus of Elasticity	72 to 74 GN/m ²
Specific Gravity	2.68
Strain at breaking point (strand)	2 to 2.5%
Filament diameter	13 to 20 μm ± 2 μm

Pre-chopped strands are used in premix GRC and as a reinforcement in render material. Continuous rovings for chopping immediately prior to spraying are used in the spray application of GRC.

Chopped Strands consist of strands chopped into uniform length while maintaining the integrity of the original strand. They are available in lengths of up to 25 mm of which 12 mm and 25 mm are standard lengths. Chopped strands are normally designated by length, by the Tex of the individual strands and by reference to their size coating. The size coating on chopped strands is designed to control the dispersion of the strand into filaments. Some are designed to disperse into filaments during mixing while others maintain integrity.

A Roving is a grouping of individual parallel strands wound as a bundle into a cylindrically shaped package containing typically 20 kg of fibre. It may be:

- Chopped at the GRC manufacturing plant, thus minimising the difficulties in transporting, handling and feeding already chopped strands.
- Chopped in a 'gun' and sprayed simultaneously with a matrix material to provide composites which may be of complex profile.

Rovings are designated by the Tex of the bundle and by reference to their size coating.

4.2 CEMENT

Australian cements for use in GRC should conform to AS 3972–1997 and include:

- Type GP (General purpose Portland cement)
- Type GB (General purpose Blended cement).

Additionally, in architectural cladding, off-white and white cements may be used. There is no specific Australian

Standard for these cements but they could be expected to perform in both the plastic and hardened state similar to Type GP. Considerable care is required during cement storage and the manufacture, curing and handling of GRC products made with these light-coloured cements to avoid contamination and discolouration.

Special purpose cements, in AS 3972 are identified as:

- Special purpose type HE (High Early strength)
- Special purpose type LH (Low Heat)
- Special purpose type SR (Sulfate Resisting)

There is likely to be only limited application of these Special purpose cements in GRC manufacture.

Storage of cement is critical to its performance.

- Bagged cement should be stored under cover, off the ground, separated by type and used on a first-in/first-out basis. It could lose up to 20% of its strength after 4–6 weeks storage.
- Bulk cement should be stored in airtight silos and should be satisfactory for use for up to 3 months.

4.3 FILLER MATERIAL

4.3.1 Sand

The use of well graded sand provides economy and assists in reducing shrinkage of the product.

Sand as fine aggregate should conform to AS 2758.1–1998.

- Cleanliness
All sand should be free of soluble matter and fine silt and clay-size particles. Washing may occasionally be necessary.
- Particle Shape/Texture
Particle Shape – rounded or irregular preferred. Flaky and/or elongated particles should be avoided.
Surface texture – smooth preferred. Honeycombed surfaces should be avoided.
- Chemical Composition (%) to AS 2489 include:
Sands of the following composition have been used and have been found to be satisfactory.

Silica	> 96%
Moisture	< 2%
Soluble salts (ie alkalis)	< 1%
Loss on ignition	< 0.5%
Organic matter	must not affect the setting of the cement
SO ₃	0.4 (4000 ppm) max
Cl	0.06 (600 ppm) max

■ Grading

- (a) For sprayed GRC
 - 1.18 mm max (ie 100% passing AS 1152 test sieve of 1.18 mm opening).
- (b) For sprayed premix GRC
 - 2.36 mm max (ie 100% passing AS 1152 test sieve of 2.36 mm opening).
- (c) Fine fraction
 - 10% max passing a 150 micron (AS 1152) sieve opening.

NOTE: Evidence is available that sands not precisely conforming to the above requirements may be suitable. Local experience should be considered.

Loss on ignition can be accepted up to 3%, providing the material is hard, non-crushable, non-reactive and of similar shape and grading to that described above.

4.3.2 Crushed Aggregates

Many varieties of aggregates used for concrete may be crushed to a suitable grading for use in GRC. Examples of such aggregates are marble, limestone and granite. Properties of such aggregates should be in accordance with AS 2758.1 and AS 1141. As a general rule, aggregates should not exceed 14 mm.

4.3.3 Fly Ash (pulverised fuel ash)

Fly ash is a finely divided pozzolanic material extracted from the flue gasses of boilers that use pulverised coal as the firing material.

Whilst not itself a cementitious material, it will react with calcium hydroxide, liberated during the hydration of portland cement and in the presence of moisture provides cementitious qualities. Fly ash may be incorporated in Blended Cements or added directly to the mix.

Fly ash for use in GRC should comply with the requirements of AS 3582.1 *Supplementary Cementitious Material for use with Portland Cement*. The rate of strength gain of mixes using fly ash could be expected to be slower than that of a portland-cement-only mix.

4.3.4 Granulated Blast Furnace Slag

Granulated Blast Furnace Slag is a prepared residue of the steel-making operation. It is non-metallic in nature, consisting largely of silicates and aluminates. It is described as a material having latent hydraulicity; that is to say, most slags will not set, or do so only slowly in the presence of water but will behave as hydraulic cements in the presence of activators such as calcium hydroxide liberated during the hydration of the portland cement.

Similarly to fly ash, mixes incorporating ground blast furnace slag could be expected to develop strength more slowly than cement only-mixes. Granulated Blast Furnace Slag for use in GRC should conform to AS 3582.2.

4.3.5 Silica Fume

Silica fume consists of extremely fine particles of amorphous silicon dioxide possessing active pozzolanic properties. It is used as a partial replacement for cement but can increase water demand due to its high surface-area to volume characteristics. This may be countered by the use of HWR admixtures. AS 3582.3 refers.

4.3.6 Metakaolin

Metakaolin, a pozzolanic derived from a calcined china clay, rigorously controlled to ensure its compatibility with the hydration properties of portland cements. Research work using standard and derived aging tests point to superior performance in strength and toughness over a 25-year equivalence.

4.4 WATER

Water for use in mixing should conform to AS 1379 Section 2.4.

4.5 ADMIXTURES

Standard concrete admixtures or those specially formulated for GRC manufacture may be used as appropriate to the particular process and to obtain the required properties of GRC. Admixtures are generally added to produce the following effects.

In the manufacture of GRC:

- Increasing the workability without increasing the water/cement ratio.
- Improving the cohesion (the capacity of the mix to hold together during handling and working)
- Reducing segregation.
- Reducing bleeding.
- Retarding the setting (stiffening) process.
- Accelerating the setting (stiffening) process.

On the properties of hardened GRC:

- Increasing the rate of early strength development.
- Increasing the strength.
- Decreasing the permeability.
- Improving fire resistance.

Admixtures are added to mixes in small amounts and care must be exercised to ensure that only the correct dose as specified by the manufacturer is added. Calcium chloride is normally acceptable as an admixture except when ferrous metal fixings are used.

Where applicable, admixtures should conform to AS 1478, *MP20 Concrete Admixtures*.

4.6 PIGMENTS

Oxide pigments may be used to provide integral colour to the GRC. In the absence of a recent Australian Standard, refer to BS 1014.

Dosage rate is expressed as a percentage of the cement content of the mix by weight. Organic and synthetic oxides are available, the latter being considered superior in terms of their colour fastness and intensity.

Note the impact (generally a dulling effect) of the cement upon the oxide colour. Different brands of grey cement have differing shades of grey and this must be taken into consideration. Where light or pastel colours as required, white or off-white cement should be used.

Dosage rates should be accurately monitored.

4.7 FACING MATERIALS

Where fine and coarse aggregates are used for exposed finishes on the face of GRC panels, they should be clean, hard, strong, durable and inert, and free of material which may cause staining.

Aggregates should conform to AS 2758.1 except for gradation which can deviate to achieve the texture mutually agreed to by the client and panel manufacturer. Aggregates should be non-reactive with cement and available in particle shapes required for good GRC. The method used to expose the aggregate in the finished product may influence the final appearance. Weathering of certain aggregates may influence their appearance over time.

Veneers such as natural stone, thin brick, ceramic tile or terracotta may also be used as facing materials. Compatibility of the facing material to the backing should be considered when developing mix designs. A bond breaker with flexible mechanical anchors may be used with natural stone facings to minimise differential movement which may otherwise induce panel bowing and/or high stresses in the GRC skin.

4.8 PANEL FRAME

The panel frame for a GRC panel may be fabricated from light-gauge steel and/or structural steel sections. Light-gauge steel materials should be either painted or galvanised to inhibit corrosion. Hot dip galvanising of the frame after fabrication is not recommended due to problems associated with distortion during galvanising.

Corrosion protection treatment should be specified by the designer in the light of the in-service conditions likely to be experienced.

Painted light-gauge steel should conform to AS 1538 *Cold Formed Steel Structures Code* and should be prime-painted with a rust-inhibiting paint conforming to

AS 3885 and AS 3750.9. This steel should be galvanised in accordance with AS 1650. Gauge and size of studs, tubes and frames should be shown on the approved shop drawings.

Structural steel tubes should conform to AS 1163. Member size should be shown on the approved shop drawings. All welding should be to AS 1554.1.

4.9 ANCHORS AND INSERTS

Steel bars for anchors should conform to the appropriate requirements of AS 3679. Yield strength should conform with design minimum and maximum steel yield strengths.

Anchors incorporated in the GRC skin should be corrosion resistant. Materials should conform as follows.

For materials which are:

- galvanised AS/NZS 4534:1998 *Hot Dipped Galvanised Coatings on Ferrous Articles*
- zinc plated AS 1789:2003 *Electroplated Coatings - Zinc on Iron and Steel*

Inserts should be compatible with or isolated from the other materials with which they will come in contact in order to avoid unwanted chemical or electrochemical reactions.

Dissimilar metals should not be placed in contact with each other unless experience has shown that no detrimental galvanic action will occur. Hardware protected with paint, galvanising or plating should be made good if the coating is damaged. If welding is required as part of the field assembly, the welded area should be cleaned and made good with a zinc-rich primer.

Ductile materials should be used.

The allowable load on an insert moulded into the GRC skin should be determined by the results of controlled tests duplicating the loading condition in which the insert is used. Many inserts used in GRC panels have been designed and tested by the insert manufacturer for use in precast or cast-in-place concrete. Inserts for use in GRC require aged testing to determine their suitability.

4.10 HANDLING AND LIFTING DEVICES

Handling and lifting devices should be fabricated from ductile material since they are subject to dynamic loads. They should be designed to lift and transport the GRC panel in its various positions (considering special loadings such as wind or impact) with an appropriate factor of safety. When permanent connection hardware is used for handling, it should be properly designed for such additional service without any danger of subsequent damage to such connections or their performance.

4.11 CONNECTION HARDWARE

Miscellaneous structural shapes used to support or attach GRC panels to the structure should be fabricated from steel conforming to AS 4100 and AS 3679. Light-gauge shapes should conform to AS/NZS 4600. Connection hardware should be painted or galvanised.

Corrosion protection treatment should be specified by the designer in the light of the exposure and in-service conditions to be expected.

4.12 INTEGRAL RIB FORMERS

Rib formers may be used to produce ribs that provide structural rigidity and stiffness for the GRC panels. Expanded polystyrene foam and polyurethane foam are the most common materials used. Care should be exercised in the use of these materials where ambient, in-service temperatures are greater than 60°C.

Hollow sections can be made by using cardboard shapes to form the void and then overspraying with a GRC backing mix.

4.13 WELDING

The welding of panel frame members should be by shielded metal arc welding (SMAW) or gas metal arc welding (MIG). All welding requirements should conform with AS 1554.

All welding consumables should conform with the appropriate Australian Standards. AS 1553, AS 1554, AS 1858, AS 2717, AS 2203.1 refer.

4.14 HEALTH AND SAFETY ASPECTS

4.14.1 Materials Safety Data Sheets

Where necessary, manufacturers should have available for inspection MSDS relating to raw materials.

4.14.2 Fibre

Fibres from 13 to 20 microns in diameter are substantially above the range of respirable particles. Evidence to date has shown that these fibres cause no long-term health hazard, although some temporary skin irritation may be experienced.

4.14.3 Other Component Materials

The component materials manufacturers' recommendations regarding the handling and use of all materials used in the manufacture of GRC should be followed by the GRC manufacturer.

Referenced Documents

The following documents were referred to in Chapter 4, in order of appearance:

- AS 3972:1997 *Portland and Blended Cements*
- AS 2758.1:1998 *Concrete Aggregates*
- AS 1141:1999 *Methods for Sampling and Testing Aggregates*
- AS 2489:2003 *Methods for the Analysis of Zircon Sand Concentrate*
- AS 1152:1993 *Specification for Test Sieves*
- AS 3582:1998 *Supplementary Cementitious Materials for use with Portland Cement*
- AS 3582.1:1998 *Fly Ash*
- AS 3582.2:2001 *Slag – Ground Granulated Iron Blast Furnace*
- AS 3582.3:2002 *Silica Fume*
- AS 1379:1997 *Specification and Supply of Concrete (Section 2.4)*
- AS 1478:2000 *Chemical Admixtures for Concrete*
- BS 1014:992 *Specification for Pigments for Portland and Portland Cement Products*
- AS/NZS 4600:1996 *Cold-Formed Steel Structures*
- AS/NZS 3750.16:1998 *Paints for Steel Structures - Waterborne primer and paint for galvanized, zinc/aluminium alloy-coated and zinc-primed steel*
- AS/NZS 3750.9:1994 *Paints for Steel Structures - Organic zinc-rich primer*
- AS/NZS 4534:2006 *Zinc and zinc/aluminium-alloy coatings on steel wire*
- AS 1163:1991 *Structural Steel Hollow Sections*
- AS/NZS 1554 (Set):2004 *Structural Steel Welding Set*
- AS/NZS 3679.1:1996 *Structural Steel - Hot Rolled Bars and Sections*
- AS/NZS 3679.2:1996 *Structural Steel - Welded I Sections*
- AS 1789:2003 *Electroplated zinc (electrogalvanized) coatings on ferrous articles (batch process)*
- AS 4100:1998 *Steel Structures*
- AS/NZS 1553.1:1995 *Covered electrodes for welding - Low carbon steel electrodes for manual metal-arc welding of carbon steels and carbon-manganese steels*
- AS 1858.1:2003 *Electrodes and Fluxes for Submerged Arc Welding - Carbon steels and carbon-manganese steels*
- AS/NZS 2717.1:1996 *Welding Electrodes – Gas Metal Arc*
- AS 2203.1:1990 *Cored electrodes for arc-welding - Ferritic steel electrodes*

5 GRC MANUFACTURE

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5.1 PANEL MANUFACTURE – GENERAL

GRC panels should be obtained only from those manufacturers who possess a demonstrated capability to produce products of reliable and consistent quality. These manufacturers must show that they have the required plant and equipment, experienced production personnel, and the quality control procedures necessary to manufacture panels having the designed performance characteristics, all at the required rate of production.

5.2 MANUFACTURING METHODS

5.2.1 Sprayed GRC

In the manufacture of GRC by the spray process, simultaneous sprays of cement/sand mortar slurry and chopped AR glass fibre are deposited from a spray-head into or onto a suitable mould. The spray-head may be hand held or mounted on a machine. The mortar slurry is fed to the spray gun from a metering pump unit and is broken into droplets by compressed air. AR glass fibre roving is fed to a chopper/feeder, mounted on the spray head which chops the fibre to pre-determined lengths, typically 25–40 mm, and injects the chopped strands into the mortar spray so that a uniform layer of fibre and mortar is deposited onto the mould. The slurry has typically a sand:cement ratio of 1:1 and a water/cement ratio of 0.33. Admixtures may be used to improve workability. Typically, fibre content is in the order of 5% by weight of slurry.



Photograph 5.1 Manual spraying in progress

5.2.2 Manual Spray Method

The mix is sprayed into the mould, the operator directing the stream of material perpendicular to the mould surface, until the appropriate thickness of GRC has been built up. Roller-compaction ensures compliance with the mould face profile, impregnation of the fibre by the slurry, removal of entrapped air and development of adequate density. The rolled surface may be finally trowelled smooth. Thickness control is achieved by use of pin-gauges. The process results in one surface of the product having an ex-mould finish and the other surface a rolled or trowelled finish. This process is capable of producing complex shapes.

5.2.3 Mechanised Spray Method

Mechanised spray techniques can be readily used for the production of components that are substantially flat or of shallow profile; moulds are propelled along a roller or flat conveyor passing beneath a transverse moving unit on which the spray-head is mounted.

5.2.4 Spray-Dewatering Process

This process utilises the principles of the mechanical spray equipment described above to form a continuous GRC layer which is then dewatered to consolidate it and produce a workable sheet material which may be allowed to set in the flat state; alternatively, it may be formed whilst still in the 'green' state to produce corrugated or profiled sheets, box sections, pipes, etc.

5.3 PREMIXED GRC

All premix processes involve the blending of the cement, sand, water, admixtures and chopped strands of AR fibre in a mixer prior to being formed.

To produce a premix of the correct quality it is necessary to mix in two stages. The first stage is designed to produce a high quality slurry to achieve the necessary workability and allow for the uniform incorporation of fibre. The second stage is the blending of fibres into the slurry. Usually, a two-speed mixer mixes the slurry at higher speed and blends in the fibre at a lower speed to prevent fibre damage.

The actual mix formulation used depends upon the type of product being made.

A typical mix has a sand:cement ratio of 0.5:1 and a water/cement ratio of less than 0.35. Admixtures to improve workability may be used.

Chopped strand content is typically 3–3.5% by weight of slurry.

Fibre length is typically 12 mm with a maximum fibre length of 25 mm.

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5.3.1 Vibration Casting

This involves the pouring or pumping of the GRC premix into an open or doubled-walled mould; vibration enabling the slurry to flow and air to be removed.

5.3.2 Spraymix

This is a combination of premix and spray methods and uses normal spray equipment together with vibration casting.

5.3.3 Pressing

Rapid production of relatively simple, small components is possible by pressing techniques.

5.4 MOULDS

The appearance of the finished panel surface is directly related to the choice of mould material and the quality of workmanship of the mould itself. The in-service life of a mould is also a function of the choice of mould material which must therefore be selected with care. All moulds, regardless of material, should conform to the profiles, dimensions and tolerances indicated by the contract documents and the approved shop drawings.

Moulds should be dimensionally stable to produce the required finish and tolerance. Repeated use of moulds should not affect the dimensions or planes of the moulds beyond permissible tolerances. The mould materials should be non-absorbent or sealed to prevent excessive moisture absorption.

Ideally, all panel edges or arrises should be rounded (min. 3-mm radius) or be chamfered, with adequate 'draft' or taper to permit stripping without damage to the mould or the GRC unit. Generally, the minimum draft that will enable a unit to be stripped easily from a mould is 1:8 (25 mm in 200 mm). This draft should be increased for narrower sections or delicate units as the suction between the unit and the mould then becomes a major factor in both design and stripping. The draft should be increased to 1:6 for screen units with many openings, or for ribbed panels. Drafts for ribbed panels should be related to the depth and spacing of the ribs. Where vertical faces are required, moulds should be designed so that the vertical edges of the mould are removable or collapsible.

Moulds should be treated with a release agent that will permit release without damaging or staining the GRC and without affecting subsequent coating, painting or caulking operations.

5.5 PROPORTIONING AND MIXING

Mix design will depend upon strength requirements, density, the amount of detail, the form surface, fire rating, and other physical properties. Records should be kept of actual mixes used. This will enable correlation of the properties of cured products to the specified requirements.

Mix proportions should be left to the manufacturer's discretion to achieve adequate workability, engineering characteristics and surface finish under the specific circumstances and with available materials. Physical properties for use as design parameters will vary and must be determined from trial runs and testing prior to establishing mix proportions and control limits.

5.5.1 Face Mix

The following factors should be considered in preparing the mix design:

- Need for compatibility of the face mix with GRC backing mix in terms of volume and movement change.
- 28-day compressive strength compatible with backing mix.
- Absorption < 10% by weight.
- Freeze/thaw conditions requiring the use of air entrainment (range of 3-10%).
- A maximum aggregate size not greater than 80% of face mix thickness.
- Similar water/cement ratio as the GRC backing mix.

In proportioning face mixes, attention should be given to ensuring adequate compatibility with the GRC backing and hence similar cement contents should be used. Large differences in physical properties, such as shrinkage and thermal coefficient of expansion, of the face mix and GRC backing mix may cause cracking and/or delamination. Control of W/C ratio is an important aspect of design.

GRC backing mixes have a much higher cement content than conventional concrete. Consequently, integral face mixes that have historically been used with conventional concrete may not be compatible with GRC backing mixes for the following reasons:

- Differences in initial shrinkage.
- Difference in moisture-induced volume changes.
- Differences in thermal-induced volume changes.

5.5.2 GRC Backing Mix

The spray process requires a mix that is sufficiently fluid for continuous pumping and spraying without blockages and that will allow proper compaction. Low-water-content mixes give high cured strength and simplify the spraying of near vertical mould surfaces.

The following factors should be considered in preparing the mix design:

- Physical Properties
- Water/Cement Ratio
- Cement/Sand Ratio
- Fibre Content
- Fibre Type
- Fibre Length
- Acrylic Co-Polymer Content
- Admixtures.

In general, a fibre content of 5% by weight of total mix, using 25 mm to 40 mm fibre lengths, sand:cement ratios of approximately 1:1, water/cement ratio of approximately 0.3 and an acrylic thermoplastic co-polymer dispersion used as a curing agent of 5 to 7% by weight of polymer solids to cement, provide a blend of acceptable composite properties and workability.

Mixing equipment should be capable of thoroughly blending the materials.

Consideration should be given to the pot life of the polymer and mix temperature to avoid blockage of the spray equipment. Depending upon the type of polymer being used, it may be necessary to add an anti-foaming agent.

It is important to maintain proper cleanliness of the equipment.

5.6 MIST COAT

A mist coat consists of a cement:sand slurry, often incorporating a polymer admixture. The purpose of this mist coat is to prevent the appearance of the fibres at the panel face when a facing mix is not used.

Thickness of the mist coat is critical and should be approximately 0.5 mm; thicker applications may induce surface crazing; thinner applications may permit the appearance of the fibres at the face. The GRC backing mix should be applied prior to the initial set of the mist coat.

5.7 PLACING AND CONSOLIDATING OF FACE MIX

The primary concern with the face mix is uniformity and thickness. A non-uniform face mix thickness may contribute to panel cracking. Thickness control of this unreinforced layer is important to ensure that sufficient material is available for abrasive blasting or other surface treatments. However, it is critically important that the face thickness be controlled and uniform, since the thickness of the GRC backing, to be subsequently applied, will be determined based on a measurement of the total thickness of the skin. Face mixes are generally 20% thicker than the largest aggregate size.

Sprayable face mixes should be applied in one uniform layer. Consolidation of face mixes is achieved by trowelling, tamping, rolling or vibrating. Thickness should be checked to ensure uniformity over the entire panel. Special attention should be given to placement thickness over reveals, corners and sides. Thickness should generally be the minimum possible to achieve the desired finish but must be sufficient to prevent bleeding-through of the sprayed-up glass fibre reinforced backing mix.

Face mixes should be compacted carefully to remove excess air and ensure conformity with the mould face. All corners, recesses, and reveals should be compacted with special tools made for each condition to ensure all areas of the face mix have been compacted. Mould vibration or the use of vibrating trowels are successful on flat panels. This sometimes requires a two-step face mix application on profiled moulds.

The same face mix applied or consolidated by different methods may result in varying shades and textures on the finished product. Therefore, the methods of applying and consolidating the face mix should remain the same throughout a project.

5.8 SPRAY APPLICATION OF GRC BACKING

Following application of the face coat or mist coat, the backing coat is applied in a series of layers, each layer consolidated by rolling to provide a dense product.

Each layer is typically in the range of 3–6 mm thick, sprayed in a direction at right angles to the previously placed layer.

Normal GRC backing coat thickness should be 9 mm or the design thickness, whichever is the greater.

Particular care must be taken to maintain uniform and minimum thicknesses. This is important in both flat and corner areas where rolling tends to move material away from raised corners. Thin areas produce stress points and locations for potential cracks.

Scrim may be used to reinforce areas subjected to high localised stress, eg at corners of openings, at gravity anchors, around transitions and shapes such as deep reveal lines.

5.9 SURFACE FINISHES

Finishing techniques vary considerably between individual plants. Many plants have developed specific techniques supported by skilled operators or special facilities and materials.

5.9.1 Mist Coats

A smooth or fine texture off-form finish, using a mist coat may be one of the most economical. It does, however, pose difficulties of achieving uniform colour control. The use of light-coloured cements such as off-white will reduce the problem.

The cement exerts the primary colour influence on a smooth finish. Many of the aesthetic limitations of smooth GRC may be avoided by providing a profiled or striated surface, subdividing the panel into smaller surface areas, by using a light-coloured cement, or by the use of applied coatings.

5.9

The smooth cement film on the GRC may be susceptible to surface crazing. This is, in most cases, a surface phenomenon and will not affect structural properties or durability. In some environments, crazing will be accentuated by dirt collecting in these minute cracks. This will be more apparent with light-coloured cement finishes and in horizontal more than in vertical surfaces.

5.9.2 Face Mixes

Many types of surface finishes successful with architectural precast concrete can be reproduced using GRC. The absence of large coarse aggregate in the GRC mix allows it to follow closely the surface texture or pattern of the mould. A wide variety of surface patterns and textures can be achieved by casting the panels against formliners. It is advisable to avoid sharp angles and thin projections whenever possible and incorporate chamfers or radii at inside corners of the form due to the possibility of fibre bridging.

The extent to which the glass fibres are able to penetrate surface detail depends on the scale of the detail. The surface layers of a heavily textured panel may consist of unreinforced cement/sand mortar or they may be an exposed aggregate finish.

Combination finishes involving the use of more than one basic finishing method are almost infinite. A demarcation feature or a skin joint should be incorporated into the surface of a GRC panel having two or more different mixes or finishes. The different face mixes should have reasonably similar behaviour with respect to shrinkage in order to avoid cracking at the demarcation feature due to differential shrinkage.

The cement matrix also offers a wide choice of colour variations through the use of grey, white or buff coloured portland cements or through the use of colour pigments. It should be noted that colour variation between panels will be directly proportional to the colour intensity. The darker the colour, the greater the possible colour variation.

Sample panels of adequate size may be necessary to translate design concepts into realistic production requirements.

Exposed aggregate surfaces may be achieved by removing the surrounding paste using chemical processes, such as surface retarders or acid etching, or by mechanical means using abrasive blasting, honing and polishing. Each method will uniquely influence the appearance of the exposed surface.

Exposed aggregate and polished finishes may need cleaning to remove laitance by washing with dilute hydrochloric or muriatic acid. Solutions of 2–5% acid in water are commonly used.

Where aggregates are exposed at the panel surface, ie polished, abrasive blasting, etc, it is advisable to blend the matrix colour to approximate to that of the exposed aggregate. Blending can be achieved by careful selection of cement and sand or by the addition of small quantities

of oxide pigment, possibly in the order of 0.5–2% of oxide by weight of cement. Such matrix blending will measurably reduce or eliminate discolouration due to minor aggregate segregation.

5.9.3 Veneers

Materials such as natural cut stone (granite, limestone, marble), brick slips, ceramic or quarry tile, and architectural terra cotta provide a great variety of veneer finishes for GRC. Quality requirements (design and production procedures) for these finishes should be based on previous records with the identical materials, or sufficient testing of sample and mock-up units to establish performance criteria under the envisaged service conditions. Particular attention should be paid to the compatibility of materials with respect to differential expansion and contraction caused by thermal and moisture changes. It is necessary to consider the differential volume change of veneer facings and GRC backing.

Sample panels of adequate size are necessary to translate the concept into a realistic production programme.

A complete bondbreaker between a natural stone veneer and GRC should be used. Bondbreakers may be one of the following:

- liquid bondbreaker applied to the back surface of the veneer prior to spraying GRC;
- plastic film; or
- 3-mm plastic foam pad or sheet.

Connection of the natural stone to the GRC should be with mechanical anchors that can accommodate some relative movement due to differential volume change.

Cracking can occur in the GRC backing if the veneer anchorage provides excessive restraint. This is particularly critical where the face materials are of large surface area. The introduction of skin joints in the GRC and/or the limiting of the size of the stone pieces may be necessary to provide a properly functioning system. Attention to detail during design and fabrication is critical to ensure that differential volume change is accounted for.

Several different styles of stone veneer anchors are available. Three examples are shown in **Figure 5.1**. The anchors should be of stainless steel with a diameter of 4 mm or 5 mm. They are similar to those used in veneer-faced precast concrete, but may be modified to account for the thin section of GRC. The spacing and quantity of anchors are dependent upon:

- Flexural strength of the stone
- Thickness of the stone
- Strength of the GRC backing
- Strength of the anchor assembly.

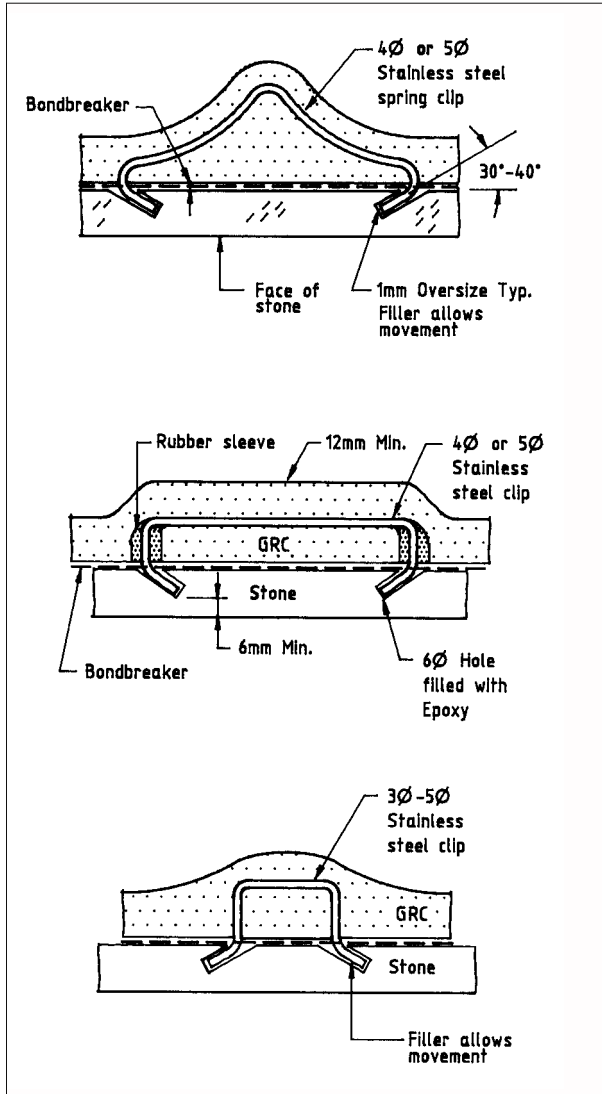


Figure 5.1 Typical anchor types

Anchor placement can vary, based on the results of the tests performed on the stone and anchor assembly. The minimum ratio of test load to service load should be five to one.

Terra cotta, if used, should be treated similarly to natural stone veneers.

5.9.4 Coatings

Coatings may be used for decorative purposes. Each coating type is formulated to give certain performance under specific conditions. Since there is a vast difference in coating types, brands, prices and performances, knowledge of the composition and performance standards is necessary for obtaining a satisfactory GRC coating.

GRC is sometimes so smooth that it makes adhesion of the coatings difficult to obtain. Such surfaces should be lightly sandblasted or lightly acid etched, to provide an adequate substrate for the coating system.

The application of a coating may vary from a relatively permeable acrylic coating to highly impermeable coatings such as some polyurethane systems. For impermeable coatings, particular attention should be given to the reduction of the moisture content throughout the entire panel. The moisture content should be less than 5%, whilst the pH level must be reduced to less than 10. The moisture and pH levels must be uniform throughout the entire surface of the panel. Particular attention should be given to these two factors in areas of increased thickness such as structural ribs, attachment points and returned edges.

5.10 PANEL FRAME

Most GRC panels are fabricated using a panel frame to provide stiffening and structural support. The frame is generally made using light-gauge steel or a combination of structural sections and light-gauge steel.

Loads from the panel skin are transferred to the panel frame through flex, gravity and, in some cases, seismic anchors.

The panel frame transfers panel loads to the building frame, supports installed window loads and acts as a grid support for the interior insulation, fire stops and interior wall coverings. The studs and anchor spacings are based on design considerations, typically at 600-mm centres.

These anchors must be designed and welded to the frame to accommodate moisture and thermal movement of the skin without imposing excessive restraint. Oversized, incorrectly welded, incorrectly positioned or embedded anchors can cause undue restraint resulting in stresses sufficient to crack the skin.

In the course of manufacture, storage, transport and erection, the prefabricated panel frame will be moved several times. Welded rather than screw connections are therefore desirable, although both methods are used.

When light-gauge steel is welded, it should be a minimum of 16-gauge material. Care should be taken when welding plates and angles to the light-gauge steel to prevent burn-through, since this can significantly alter the section properties of the member and the strength of the welded connection. Care must be taken when welding plates and angles to the light-gauge metal studs. If thick hardware, such as plates or angles for bearing connections, is required, supplementary thin plates or angles should first be welded to the studs as a base for welding the thick hardware to the stud frame. Welding should comply with AS 1554.1. Wire feed welding and Gas Metal Arc Welding (GMAW) and Shielded Metal Arc Welding (SMAW) are commonly used.

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Accessible welds on corrosion protected material (galvanised or painted) should be slagged and made good after welding.

Following fabrication, the panel frame is ready to be attached to the GRC. After the GRC is sprayed and roller compacted to its design thickness, the panel frame is positioned over the skin by jigs or brackets. The panel frame should be installed before the GRC backing reaches initial set.

Unless specifically designed to be within the face, the flex anchors should not protrude into the fresh GRC. The pressure of the anchor compresses the GRC and changes its density and water/cement ratio in that area and may cause a blemish or shadow mark on the exterior finished face.

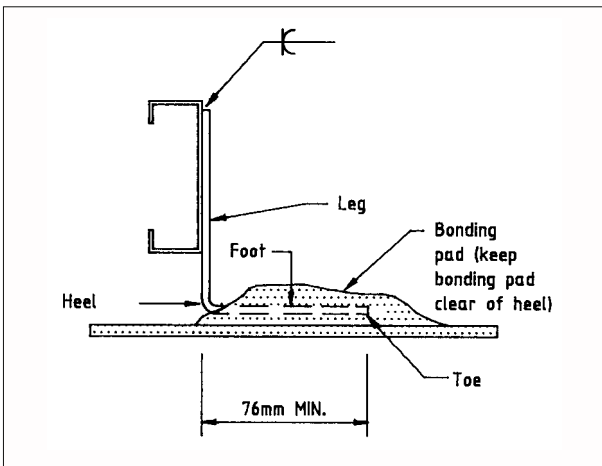


Figure 5.2 Typical flex anchor

For production convenience, the flex anchors are usually set from 3 to 10 mm away from the surface of the GRC backing.

Contact between the panel skin and the panel frame will impose restraint to movements of the skin. Therefore, the clearance between the skin and the panel frame at all locations should be sufficient to allow the GRC to move.

Immediately following placement of the frame, GRC bonding pads are placed over the foot of each anchor and integrated into the GRC backing. The thickness of the bonding pad over the top of the flex-anchor should be a minimum of 13 mm. The effective area of the bonding pad (effective length x effective width) should be a minimum of 0.0155 m².

The bonding pad is manufactured using the hand pack method.

The operator hand applies the pad and kneads it into the GRC backing. Time delay between the final roller compaction of the GRC backing and the placement of the frame and the bonding pads should be kept to a minimum. This is necessary to ensure bonding of the

overlay. If there is a significant time delay, initial set of the backing could prevent the overlay from achieving bond to the backing and there could be possible delamination. Care must be taken not to build up the bonding pad over the heel of the anchor and thus add undue restraint to the skin.

The pad is made by the operator spraying the GRC composite into a suitable container or premixing the composite. This material is then deposited over the flex anchor contact foot and must be worked well-in to fill the void between the bottom of the flex anchor and the GRC skin.

The bonding pad installation procedures during production must replicate those used in tests to determine design values.

Broken bonding pads occasionally need to be repaired in the plant or in the field. In order to repair a broken bonding pad, the surface of the GRC skin should be roughened, and some glass fibres exposed. This area then should be cleaned of any loose debris. A latex or epoxy bonding agent should then be applied to the area and a fresh bonding pad attached to the GRC skin. Manufacturers should test the bonding pad repair procedures to establish data for use in design. Due to creep considerations, this repair technique should be limited to the repair of not more than 10% of the total anchors on a panel.

5.11 VIBRATION CAST

GRC formed by the vibration casting method may develop fibre orientation which predominates in one direction. It is very important that the manufacturer and his engineer reflect the anisotropic properties of the GRC in his design.

5.12 GRC WITH INTEGRAL GRC RIBS

The use of GRC stiffening ribs introduces its own considerations. Preformed ribs in GRC that are cast into the product will by definition already be formed and will generate stresses due to restrained movement. This must be considered at the design stage. Ribs may cause shadowing at the surface of the finished panel and also wrinkling due to the restrained movement.

Unless proven by tests, ribs formed around polystyrene formers on a green face are unlikely to achieve the same degree of compaction and therefore strength as was achieved on the face. This must be assessed by the design engineer. The use of continuous AR mats of glass in ribs is one way of increasing strength and offsetting reduced compaction effect on strength. The junction of the rib and the face, whether preformed or integrally formed, is an important area of design consideration.

5.13 SANDWICH PANELS

The coating of polystyrene beads prior to mixing and the provision of an adequate venting system is necessary to limit the production of gas and to limit the heat of hydration of the core mix which will otherwise accelerate the setting of the face skins.

Polystyrene bead aggregate cement (PBAC) will impose some restraints on sandwich panels. Expanded polystyrene is the preferred core material for sandwich panels. GRC sandwich panels do not have the design redund-

ancy of a panel supported on a steel backing frame. It is therefore very important to have in-house quality control systems assessing rates of hydration on particular days for the face skins and cores. Simple crushing tests on test cylinders of the core give an indication of developed tensile capacity. Vacuum demoulding is to be encouraged. Rotation of moulds is an alternative but is often

difficult for very large panels. Both methods require care to be exercised during mould stripping to negate the suction force between mould and panel surfaces.

The degree of compaction achieved on the backskin must be carefully assessed. One would not expect the same compaction and therefore not only will its strength vary from the mould face but also its behavioural pattern to temperature and shrinkage. Test panels may be subjected to alternate wetting and drying to achieve accelerated indication of long-term behaviour.

Traditionally, temperature and shrinkage for all panels has been modelled on generating an equivalent load to suit a predicted bow under shrinkage and temperature conditions. This is valid but conservative. It is preferable to model the face skin and core mixes and build up a truss model of the panel, induce extension or contraction in one face and then calculate the stresses. It is the difference between external and internally applied loading.

The assessment of moisture and temperature movement is a function of the impermeability of the coating, initial core moisture at erection and orientation of the panel with regard to the sun. Reversible and irreversible movements as predicted for conventional concrete should be used at this time.

5.14 pH LEVELS – ALKALINITY

Uncoated GRC panels made with Type GP cement are currently produced with alkaline surface pH in the range of 11 – 13. GRC panel manufacturers need to co-ordinate the required pH level in manufacture with the surface finish to be applied to the GRC.

5.15 HANDLING AND STRIPPING

These aspects will be considered in detail in Chapter 11. They affect long-term behaviour of panels and design stresses.

Referenced Documents

The following document was referred to in Chapter 5:

- AS/NZS 1554 (Set):2004 *Structural Steel Welding Set*

6 CURING

Curing is the process of maintaining bound water within the GRC product during its early life, generally by restricting evaporation. Thus, the water remains available for hydration of the cement and so develop strength and reduce permeability and shrinkage of the product.

Since hydration is also controlled by temperature, the curing process also involved the maintenance of a suitable surrounding air temperature.

6.1 GENERAL

GRC products are generally of thin section, have a low water/cement ratio and, in the case of cladding panels, may be of considerable surface area. These characteristics demand effective curing regimes to:

- a) provide adequate early strength to allow demoulding and handling;
- b) ensure the achievement of design strength;
- c) contain shrinkage which may otherwise result in cracking.

In the case of a) and b), curing provides for ongoing hydration of the cement which improves strength and bond, whilst in the case of c), it minimises the risk of volume loss, shrinkage and possible cracking.

The control of moisture loss, or alternatively, the replenishment of moisture is the basis of curing – plus the control of air temperature.

6.2 PRACTICE

In practice, curing is provided in a number of stages and by a variety of methods.

6.2.1 Pre-stripping or Demoulding

Following finishing, it is normal to wrap the mould in a clear, quality polythene film. This controls the possible loss of moisture from the GRC which could otherwise occur through evaporation and wind effects. It also assists in retaining some of the localised heat of hydration.

The initial stage of curing should provide sufficient strength to allow stripping and handling without damage to the GRC element. In some Australian locations it may be necessary to provide localised overnight heating to ensure that the temperature of the GRC is maintained above 15°C.

6.2.2 Main Curing

The main curing regime provides for continuing protection of the element against moisture loss by sunlight, wind or low humidity following stripping from the mould. Again, it is generally achieved by wrapping the element in plastic film in an area protected from strong direct sunlight. Localised humidity can be provided by the use of a mist spray.

6.2.3 Post Curing

A controlled post-cure regime may be necessary where the conditions of storage or use in service will be substantially different from the curing conditions. This phase may be simply storing the units with some measure of protection from strong direct sunlight. Whilst the strength of the GRC at this stage should be approaching its design strength, the main purpose of this phase of protection is to limit drying shrinkage.

Throughout the curing process, the GRC elements will be continuing to gain strength. It is important that methods of handling and storing reflect the level of strength achieved.

6.3 ACCELERATED CURING

Accelerated curing techniques are available, including low-pressure steam curing and the use of chemical accelerating admixtures.

6.3.1 Low-Pressure Steam Curing

In colder climates this method of curing may offer economic advantage in terms of mould re-use. Temperatures in excess of 50°C are not recommended and are believed to be injurious to long-term strength.

6.3.2 Chemical Accelerating Admixtures

Whilst dealt with here under the main heading of *Curing*, such admixtures are essentially involved with the development of high early strength, useful in cold conditions and to facilitate early stripping. The curing regimes mentioned earlier in 6.2 should still apply.

6.3.3 General Comment

As a practical guide to curing, GRC products subjected to the regimes described in 6.2 above, where the main cure is 7 days duration at an R/H of 95% or more, will achieve a substantial proportion of their ultimate strength.

6.4 CURING OF MIXES WITH POLYMER

An alternative method of curing the GRC is to incorporate polymeric materials into the GRC mix. The polymer formulation used must be capable of forming a film around the mix particles, thus allowing the moisture in the GRC to be retained and hydration to continue. The polymer materials are normally added at dosage rates of between 2% and 7% of polymer solids to cement weight. After demoulding, the GRC product can be allowed to cure in ambient air conditions, but care must be taken to ensure that the air temperature is above the minimum film formation temperature of the polymer.

The polymer in the mix creates a film on the backing which holds the moisture in the panel and eliminates the need for 7 days moist curing. At temperatures above 15°C, the film forms during the first 3 hours after placing.

Panels should remain uncovered for at least the first 2 to 4 hours after manufacturing. Moisture should not be allowed on the panel during this time as it causes loss of film-forming ability. Panels should remain in a covered area for 7 days whilst curing.

All polymer dispersions have a minimum film formation temperature (MFT) below which the polymer spheres will not coalesce to form a tough, durable film. Temperatures must be maintained above the MFT until the film formation process is completed. The recommended minimum panel curing temperature of 15 °C should be maintained for 24 hours. At higher panel temperatures, film formation will be accelerated. Panels should be protected from excessive air movement for the first 16 hours.

The properties of GRC cured in this way are similar to those of the same basic formulation (ie sand/cement ratio, water/cement ratio and glass content) made without polymer additions and moist cured as described in Section 6.2.

Note that the addition of polymer materials to GRC may affect the fire performance properties.

6.5 CURING – THE IMPACT OF NEW MATERIALS

New materials are constantly being developed for use in GRC which impact upon the curing techniques. Typical of these materials is Cem Star Metakaolin. The change of pore structure of the GRC resulting from the metakaolin presence means that two days moist curing at a RH of 95% is adequate.

6.6 EFFECT OF CURING UPON DESIGN

Quality curing is essential in the development of the strength of the GRC, the control of volume change and control of permeability. It is a critical aspect of manufacture which affects the long-term properties of GRC.

7 PHYSICAL PROPERTIES

7.1 GENERAL

The physical properties of GRC depend greatly on the cement matrix mix composition, glass fibre content and its length and orientation in the composite, and the overall quality of workmanship provided during the manufacturing process. Therefore, the physical properties of GRC to be used in design must be determined for each individual manufacturer and each matrix mix design.

Early age (7- and 28-day) properties of GRC are typically used to determine appropriate design parameters for the aged material and to monitor quality control throughout manufacture. Early age GRC is a relatively strong, tough, pseudo-ductile material. It must be anticipated that most GRC will exhibit permanent and gradual reductions in aged strength and strain capacity when exposed to an outdoor environment (natural ageing). The rate at which natural ageing of GRC occurs is environment-dependent. However, GRC products exposed to an outdoor environment will, in most cases, reach a fully aged condition well within the intended life span of the product. It is noted that some new GRC formulations retain high MOR and strain capacity after ageing and hence the designer should account for strength loss with respect to the GRC material to be used. Therefore, GRC products must be designed by the engineer to ensure that stresses resulting from handling, erection and in-service conditions are kept within the strength and strain limits of the fully aged material.

7.2 FACTORS AFFECTING PHYSICAL PROPERTIES

Variations in matrix composition can result in variations in composite physical properties. Cement:sand ratios ranging for 1:1 to 3:1 have been successfully used within the industry. Gradation of the sand used for slurry mixes may vary according to available supply. Performance of general purpose cements used by the industry can vary from one source of supply to another but must meet the requirement of AS 3972–1997. Several different polymer emulsions are currently available for use by the industry as curing agents. Therefore, matrix mix constituents and physical properties can vary considerably from one manufacturer's plant to another. Manufacturers should be aware of the potential variations in the physical properties of GRC resulting from changes or modifications in the cement matrix composition.

Fibre content, length and orientation primarily affect the early tensile and flexural ultimate strengths. The GRC industry typically targets a glass fibre content of 5% – by weight of total mix. Past experience has established this fibre content to be optimum for the mix designs used within the industry. Lower fibre contents result in generally lower ultimate strengths. Greater fibre contents may make compaction more difficult.

Fibre length can also affect composite ultimate strengths and compaction and consolidation. For sprayed GRC, the optimum fibre length is 30 to 50 mm. Shorter fibre, although easier to spray, will not provide maximum reinforcement efficiency. Longer fibre may cause problems with fibre and slurry laydown during spray-up, as well as compaction and consolidation problems during rolling.

The orientation of reinforcing fibres can affect composite physical properties. Sprayed GRC composites have a two-dimensional random fibre orientation. However, if care is not taken during production, fibres can become unintentionally aligned parallel in one direction or another, resulting in a composite with significantly different properties when tested along different axes.

GRC composites must also be compacted and consolidated to achieve adequate fibre embedment and composite density, as well as the required design thickness. Failure to achieve adequate composite compaction and consolidation will have an adverse effect on strength properties.

Flexural and tensile strength and modulus of elasticity vary directly with density. Poor consolidation can also lead to composite deterioration due to freeze/thaw conditions.

The required (design) thickness for GRC is determined by the design engineer. Since GRC is a relatively thin-section material, very small thickness variations will have significant effect on skin stresses. Therefore, GRC thicknesses must always be within the thickness tolerances specified (typically +4 mm, -0 mm).

Good curing results in satisfactory hydration of the cement and is necessary for ensuring fibre and matrix dependent properties. Normally, good practice requires a 7-day minimum moist curing period for portland-cement-based products, with a 2-day minimum required for polymer GRC or as nominated by the suppliers.

7.3 TENSILE AND FLEXURAL STRENGTHS

The primary properties of GRC used to establish limiting design stresses are the 28-day Limit of Proportionality (LOP) and Modulus of Rupture (MOR). As later discussed in Chapter 8, limiting design tensile stress in GRC is based on the assumed aged flexural ultimate strength. Unless otherwise approved, it is recommended that the assumed aged MOR is determined based on the average 28-day flexural yield and ultimate strength of 20 consecutive tests (6 specimens each spray-up) performed by the manufacturer prior to design also being subject to accelerated age testing.

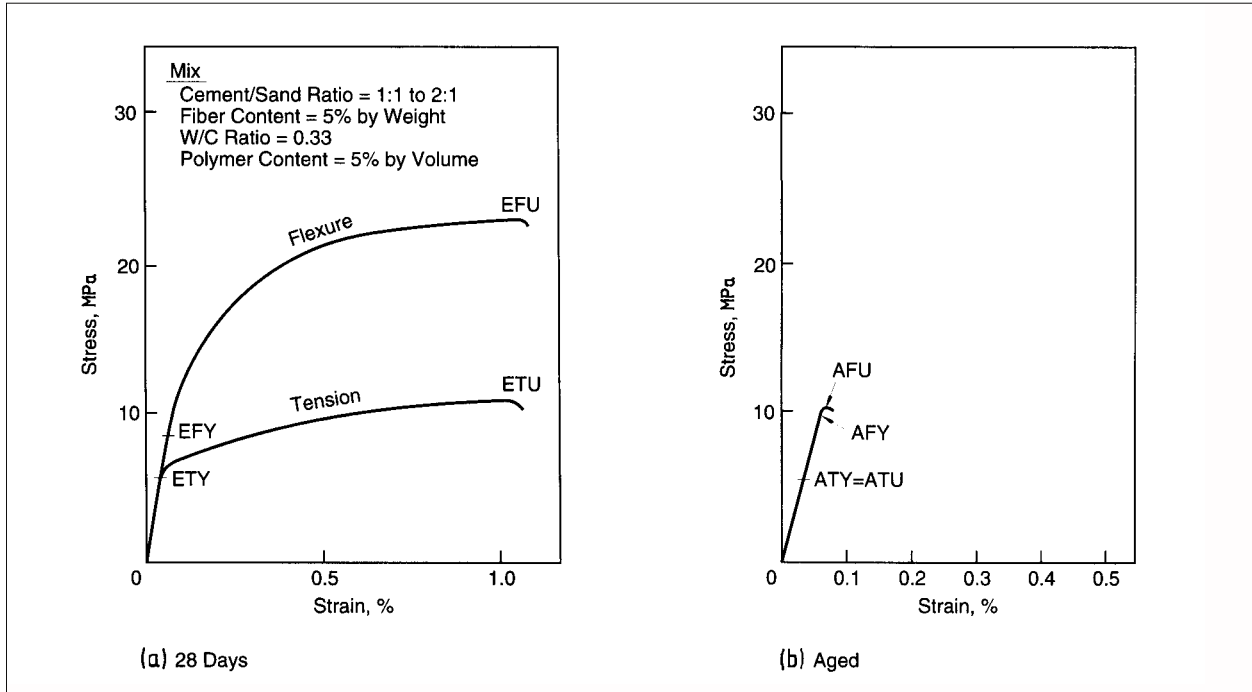


Figure 7.1 Stress/strain curves

Representative stress-strain behaviour of 28-day (unaged) GRC material is shown in **Figure 7.1(a)**. Early tensile yield strength (ETY) and early flexural yield strength EFY are primarily influenced by the matrix composition, density, polymer content and curing procedures. Early tensile ultimate strength (ETU) and early flexural ultimate strength (EFU) are affected primarily by glass fibre content, fibre length and orientation, polymer content, and composite density. As GRC ages, a loss in ultimate composite strength and strain to failure occurs as shown in **Figure 7.1(b)** while the modulus of elasticity increase.

In the fully-aged condition, the ultimate strengths (ATU or AFU) are approximately equal to the yield strength (ATY or AFY). In addition, aged ultimate strengths are also approximately equal to the early yield strengths but this is very much influenced by environment and should be used only as a lower boundary in the absence of more-detailed work. For instance, a typical 21-MPa mix, coated and thus with controlled moisture movement, has a developed AFU of around 13 MPa even though the LOP is typically 9–11 MPa.

Some of the new mix formulations available are designed to reduce or practically eliminate this ageing effect. Improving the durability of the product is thus a function of specification, initial first cost and manufacture.

7.4 MODULUS OF ELASTICITY

Flexural stress-strain curves are used to determine values of modulus of elasticity for design purposes. Values of flexural modulus of elasticity will vary in accordance with water/cement ratio, sand content, polymer content, density and curing practice. Therefore, each manufacturer must determine through testing, appropriate values for modulus of elasticity to be used in design. Typically a value of 20 GPa is appropriate.

7.5 COMPRESSIVE STRENGTH

Compressive strength is essentially matrix dependent. In-plan ('edgewise') compressive strength will be somewhat lower than cross-plan ('flatwise') strength due to the layers of glass fibres affecting the continuity of the matrix (**Figure 7.2**). Cross-plan compressive strength is not influenced by the presence of glass fibres and will be about the same as the compressive strength measured on bulk matrix materials in cylinder tests.

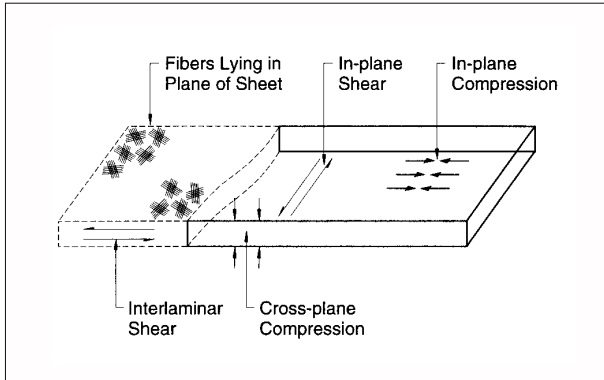


Figure 7.2 Compressive and shear strengths

7.6 IMPACT RESISTANCE

The impact resistance of GRC is influenced strongly by the reinforcing fibres. Increasing fibre length from, for example, 25 to 50 mm or using AR glass fibres with improved sizing, increases impact strength. Cured GRC at 28 days has higher impact strengths than either unreinforced cement paste or other fibre cement products. Impact properties relate to the area under the tensile or flexural stress-strain curve. As these curves alter with time, the impact properties are reduced. Normally, impact strength is not a design parameter.

7.7 SHEAR STRENGTH

Panels made by the spray-up method have fibres randomly distributed in the plane of the section. Therefore, shear values (Figure 7.2) vary with the type of load application as follows:

- Interlaminar shear. The value of shear strength is that of the matrix. This type of shear stress is encountered in the bending of single skins and in-plane load-carrying bonding pads.
- In-plane shear. In-plane shear strength and ultimate tensile strength for a range of formulations of hand-sprayed GRC after a variety of ageing treatments are identical. Therefore, in the absence of direct in-plane shear measurements, tensile strength values may be used with confidence. In-plane shear stress can be generated by bolted connections near the edge of a sheet.

7.8 SHRINKAGE

All cement based materials are susceptible to dimensional changes as they are wetted and dried. After manufacture and cure, drying results in shrinkage from the original state. 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

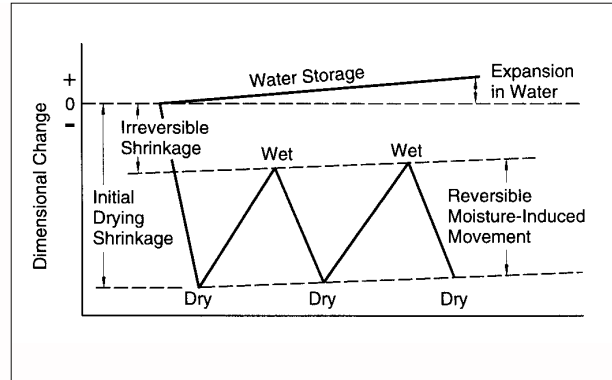


Figure 7.3 Shrinkage and moisture movement of GRC

dimensional movement dependent on the moisture content of the GRC. For GRC, the irreversible shrinkage is one quarter to one third of the total possible shrinkage; typical figures for a 0.5:1 sand:cement ratio GRC mix are 0.05% irreversible shrinkage and a total ultimate shrinkage of about 0.2%. The shrinkage and moisture movement behaviour are represented diagrammatically in Figure 7.3.

These values can be dramatically reduced by the use of recently available materials for use in GRC. Tests conducted using Cem Star plus polymer additive suggest that reversible shrinkage can be reduced to less than 0.06% for the first cycle (worst case).

It should be noted that the amplitude of reversible movement quoted above is between fully-dried and fully-soaked conditions, as in the laboratory. In practice, these extremes are not likely to be experienced in normal weathering conditions although there will be some cyclic movement about a mean level.

The moisture content of the material is related to the relative humidity of the surroundings, so it is convenient to express the dimensional change in terms of relative humidity. Figure 7.4 shows the reversible shrinkage obtained when neat cement GRC is completely derived from equilibrium with any value of relative humidity.

The ultimate shrinkage of cementitious materials is highest when the matrix is solely cement based. Shrinkage is reduced by dilution of the cement with aggregate not susceptible to moisture movement; this is standard practice for mortars and concretes and is well documented. Very early GRC employed pure cement as a matrix, but it is now normal to add a proportion of fine aggregate in order to reduce shrinkage. Figure 7.5 shows the effect of sand additions on the shrinkage behaviour of GRC.

The mechanism of shrinkage of cementitious material is complex and a number of factors affect both the magnitude of total shrinkage and the relative magnitude of irreversible drying shrinkage and reversible moisture movement. Total shrinkage is principally affected by the aggregate proportion and type, and water/cement ratio.

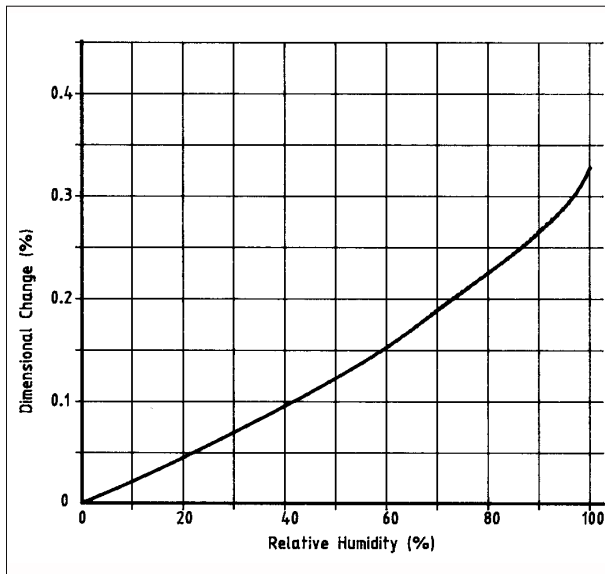


Figure 7.4 Shrinkage of a neat cement GRC upon complete drying from equilibrium with air at any relative humidity

The effect of alternative curing regimes is not conclusive for concrete but for GRC some experimental evidence suggests that GRC that has not received a sufficient moist cure undergoes increased initial irreversible drying shrinkage, up to 0.10% and overall shrinkage is increased up to 0.25%.

Since GRC is a relatively impermeable material, changes in external humidity take a considerable period of time to affect the moisture content of the GRC. 10-mm-thick sprayed GRC will take about 20 days to approach equilibrium with changes in external humidity; thicker sections take even longer. GRC used in sandwich construction panels, particularly those with lightweight concrete cores, will react much more slowly, certainly in the sense of drying out after manufacture when it is likely that equilibrium will not be reached for many months in temperate weather conditions. This clearly has implications for the design and installation of components and joints in that shrinkage movement will need to be accommodated, in order to avoid undesirable stresses in the GRC.

The general pattern of behaviour is that GRC is not susceptible to transient changes in humidity, but moisture movement in natural weather follows a seasonal pattern. An indication of this is depicted in **Figure 7.6** for the UK and similar information has been found elsewhere in the world. Superimposed on the underlying moisture movements, there may be more-rapid thermal movements. When facing materials are bonded to GRC, tests must be performed on these materials to determine shrinkage and other moisture-induced movement characteristics. Facing materials should have shrinkage and moisture-induced movement characteristics closely compatible to those of the GRC backing. Significant differences in the

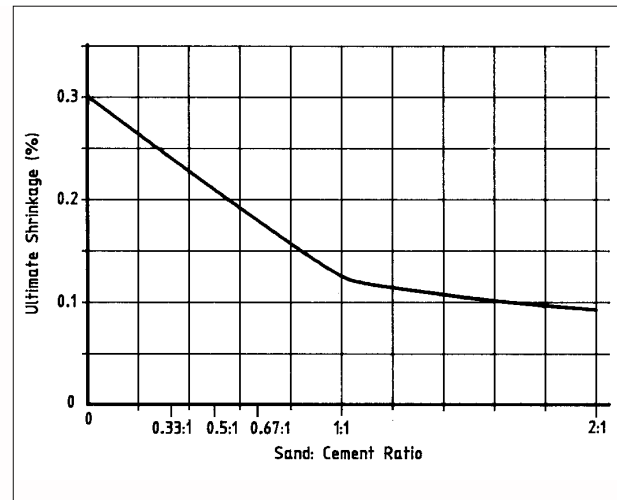


Figure 7.5 Variation of drying shrinkage rates with variable sand:cement contents

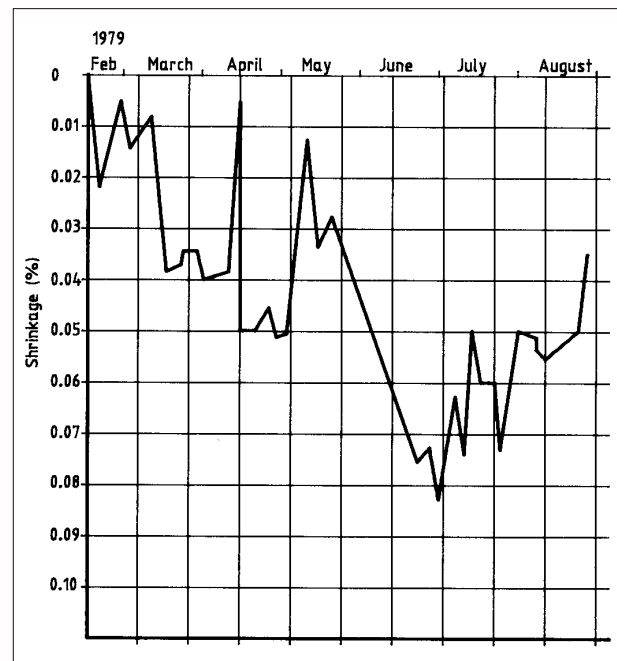


Figure 7.6 Results of shrinkage measurements in UK climatic conditions for direct spray GRC, 10-mm-thick (5% fibre content) composite, sand/cement ratio 0.5:1, water/cement ratio 0.33

characteristics of these materials can cause significant panel-skin stresses as a result of one material restraining the other from moving. Hence the need to debond some facing materials (refer Clause 5.9.3).

7.9
7.10
7.11

7.9 CREEP

GRC is capable of sustaining load over prolonged periods. Creep behaviour is similar to that of other cement-based materials. Initial elastic deformation is followed by a low creep deformation under sustained load. The creep rate decreases with time on a logarithmic basis, ie the creep deformation occurring from 100 to 1,000 hours usually approximates to that occurring from 10 to 100 hours. An exception to this general rule is found when load is applied to a saturated GRC specimen. Higher creep deformation is observed in the first hour of loading of saturated specimens than in subsequent logarithmic increments. After this time, the creep rate parallels that of materials loaded in other environments. Typical creep curves are shown in **Figure 7.7** for bending stresses below flexural yield (the normal range of working stress) under saturated conditions. Under dry conditions, creep is initially greater but approaches the creep strain under saturated conditions at later ages. Creep strain in flexure or direct tension are proportional to the initial strain, and creep strains are substantially smaller than expansion/contraction strains due to moisture changes.

Creep studies with composites indicate that these properties are controlled by the matrix. This is to be expected due to the small proportions (typically 5% by weight) of the fibre in the composite. Both water content and sand content have a significant effect on creep rates. There is no evidence of any creep effects in the composite resulting from the interaction between the matrix and the fibre.

7.10 THERMAL EXPANSION

The co-efficient of thermal expansion is typically taken as $20 \times 10^{-6}/^{\circ}\text{C}$.

GRC, in common with cement paste, exhibits an anomalous behaviour in that the thermal expansion coefficient varies with moisture content of the material. The coefficient has a value at the lower end of the range when the material is fully dry or fully saturated. At intermediate levels of moisture content (50 to 80% RH) the upper value applies. The reason for this behaviour is that the thermal expansion coefficient is made up of two movements: the normal kinetic thermal coefficient and a welling pressure, a complex effect produced by moisture transfer within the system. The behaviour for neat cement paste is shown in **Figure 7.8**.

As with concret the addition of aggregate will have an effect upon the absolute magnitude of thermal coefficient dependent upon the proportion and type of aggregate.

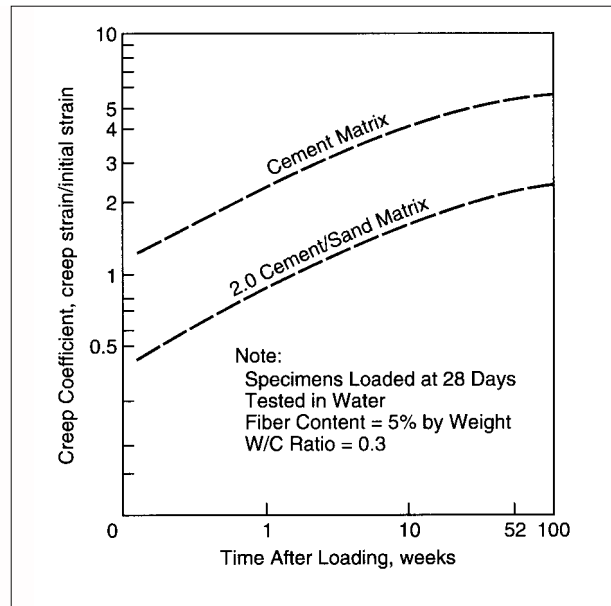


Figure 7.7 Typical creep curves

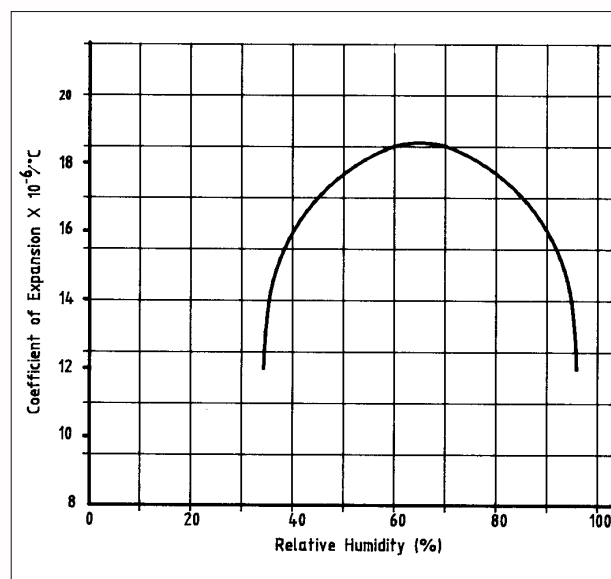


Figure 7.8 Relationship between linear coefficient of thermal expansion of cured cement paste with ambient relative humidity

7.11 CHEMICAL RESISTANCE

The rate of chemical attack on cementitious materials depends largely upon the extent to which reactive elements in the cement are exposed to aggressive agents – a function of permeability. The permeability of GRC is lower than that of normal concrete, and consequently GRC exhibits very good resistance to chemical attack.

It is generally true that dewatered GRC offers slightly better resistance than non-dewatered GRC, due to its lower water/cement ratio and reduced porosity. GRC also benefits from having a high cement content, which is another factor determining the chemical resistance of cementitious materials. Improved performance against chemical attack may be expected from the use of special cements, eg sulphate resisting cement or blended cements. Where appropriate, a chemical resistant-coating may be applied to the GRC surface.

7.11.1 Sulphate Resistance

In the presence of moisture and sulphates a reaction takes place which may cause degradation of cementitious products. GRC made using SR type cement will have improved resistance to such attack.

7.11.2 Alkalis and Acids

Portland cement releases calcium hydroxide during hydration and is highly alkaline (pH 12.5). Consequently, alkaline solutions present no particular hazard to GRC.

AR glass is relatively unaffected by acidic environments.

7.11.3 Marine Environments

Seawater and seaspray exposure of GRC give mechanical property changes similar to those in fresh water exposure and natural weather at equivalent temperature. Some surface carbonation can occur which may detract from the appearance of the GRC but is not detrimental to its mechanical properties. The rate of carbonation is normally significantly lower than that of concrete.

7.12 FREEZE-THAW BEHAVIOUR

In certain climates, GRC may be subjected to long periods at sub-zero temperatures and to freeze-thaw conditions. Laboratory tests based on BS 4624 (1981) (1992) have been carried out on both dewatered and non-dewatered, machine-sprayed GRC containing 5% fibre and various sand contents. There was no visible change in the appearance of the samples after the tests and the mechanical property values of MOR, LOP, Young's Modulus and impact strength were unchanged. The general freeze-thaw behaviour of GRC is therefore good.

Many GRC composites have now completed up to 25 years in a natural freeze-thaw environment in Toronto, Canada (average 65 freeze-thaw cycles per year) with no sign of damage.

7.13 THERMAL CONDUCTIVITY

The thermal conductivity of GRC depends on the density of the material and the moisture content.

For dry materials, ie those used in internal environments, **Figure 7.9** shows the variation of thermal conductivity with density. It is an underestimate for standard density GRC in the range of 1900–2100 kg/m³ which is used externally. For standard density GRC, dependent on the moisture content, the conductivity will be between 0.5 and 1.0 W/m°C.

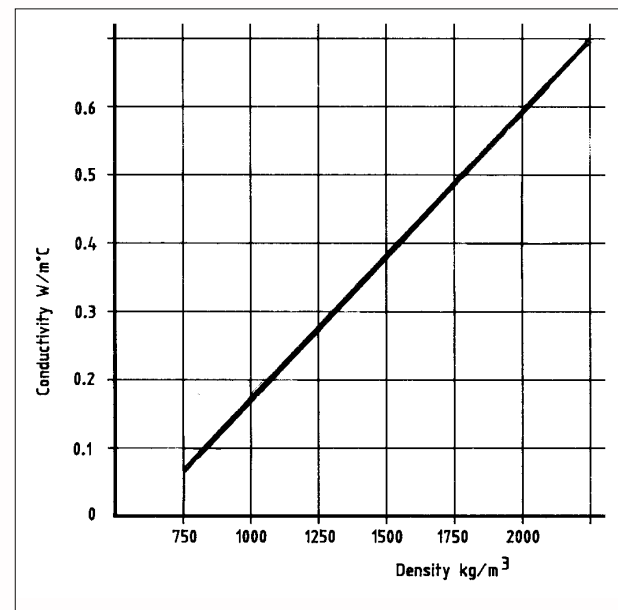


Figure 7.9 Thermal conductivity of GRC

7.14 SOUND

The sound insulation of an homogenous material depends on three physical properties:

- Surface mass (weight per unit area)
- Stiffness (dependent upon panel geometry)
- Damping.

Of these, the surface mass is the most important in determining the sound insulation at the lower frequencies.

There is a general curve relating the surface mass of material to sound reduction which is reasonably true for most homogenous materials. This 'Mass Law' curve is shown in **Figure 7.10**. The sound reduction figures shown are based on an average for frequencies from 100 to 3150 Hz. For each doubling of surface mass there is an approximate 5 dB increase in sound reduction. Hence, a typical 10-mm thickness of GRC that has a surface mass of 20 kg/m² will have an average sound reduction of about 30 dB. Increasing the thickness to 20 mm will increase the reduction to about 35 dB. Further increases in sound reduction will require a much higher overall

7.15

surface mass. It may thus become uneconomical to use single-skin GRC.

The relationship between the Sound Reduction Index and Frequency for a 9-mm (18 kg/ m²) panel is given in **Figure 7.11**.

7.15 PERMEABILITY

7.15.1 Water Vapour Permeability

Measurements of GRC water vapour permeability have been made according to BS 3177 - tropical conditions (38 °C, 90% RH). Values obtained on freshly made material range from 1 x 10⁻⁴ gm/s·MN and depend to a certain extent on the quality of compaction and curing of the GRC.

Exposure of GRC over a period of 1 to 2 years in most natural weathering conditions leads to a reduction in the permeability by a factor of about 2.

For 10-mm GRC, the above results indicate that the water vapour permeance will be less than 1.3 metric perms.

7.15.2 Water Permeance

Measurements made in accordance with BS 473.550 (now withdrawn) on freshly made 8-mm-thick GRC have shown results in the range of 0.02-0.40 ml/m²/min.

As with water vapour permeability, the water permeance tends to decrease after about 1 to 2 years natural weathering to the lower end (0.1 ml/m²/min) of the range.

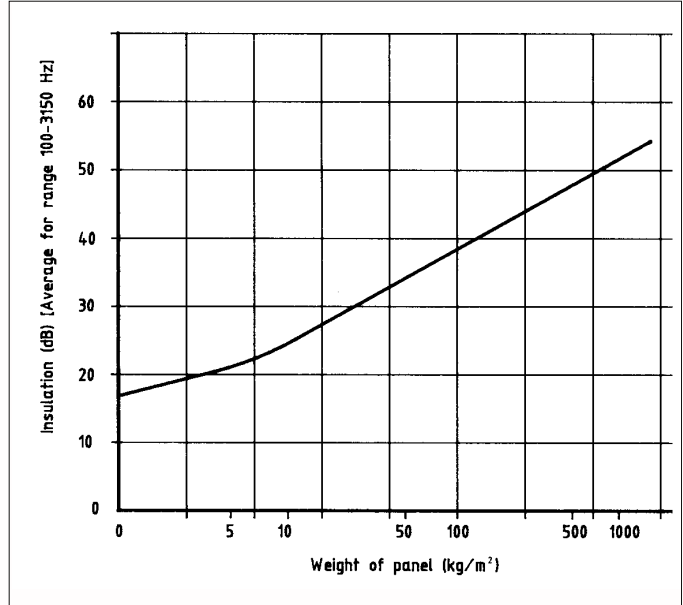


Figure 7.10 Relationship of sound insulation to mass

7.15.3 Air Permeance

Air permeance for 10-mm-thick GRC will be in the order of 2 metric perms.

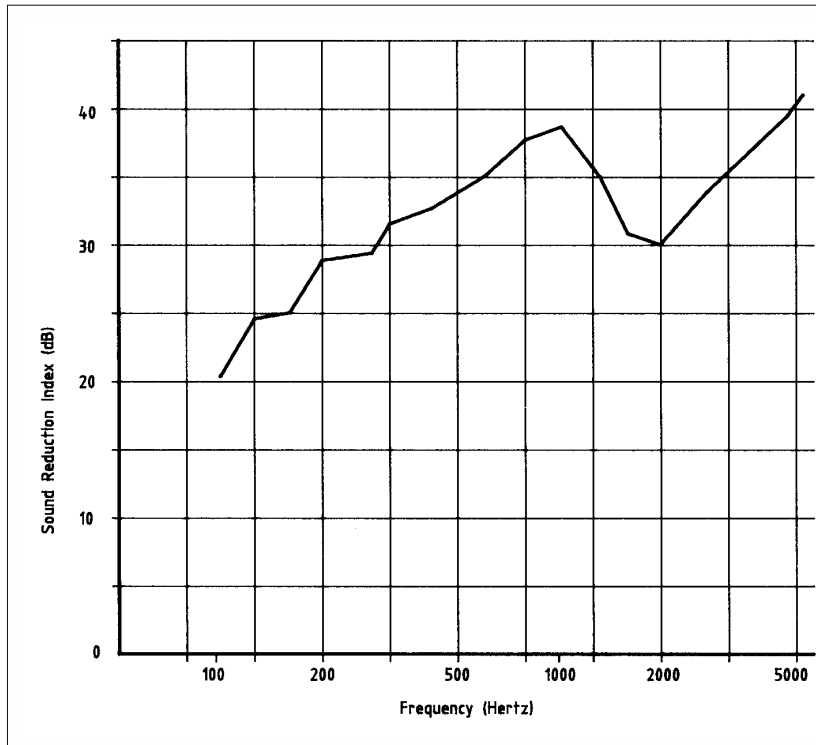


Figure 7.11 Relationship of sound reduction and frequency for a 9-mm-thick (18 kg/m²) GRC panel

7.16 ABRASION RESISTANCE

The resistance to abrasion or erosion of cementitious products can be assessed by various test methods. Care is necessary in making comparisons of the performance of materials since it is evident that a material may perform better, in a ranking sense, according to one test than to another. Test methods for cementitious products include the revolving disc test, steel ball abrasion test, dressing wheel test and shot-blast test. Following interest in the resistance of GRC to wind-blown sand, GRC has been tested according to a modified form of ASTM C418-90 which involved directing a jet of air-driven sand at the sample. Under this test, the GRC samples performed well. The results of this work, expressed as volume-loss, are given in **Table 7.1**.

Note that these values are only indicative. For example, the abrasive resistance of concrete can be increased by increasing matrix strength and using dense, abrasion-resistant coarse aggregates.

Abrasion resistance is related to density and compressive strength. GRC is thus well placed.

Table 7.1 Results of modified ASTM C419-90 tests

Material	Total Dry Volume Loss (mm ³)
Neat cement (spray dewatered)	140
GRC (spray dewatered)	207
GRC (direct spray)	300
Concrete paving slab	320
Semi-compressed a/c	370
Fully-compresses a/c	520
Brick	880

7.17 DENSITY

The dry density of standard GRC materials is commonly around 2.0 t/m³. This gives rise to a convenient method of expressing the weight of GRC, namely that 10-mm-thick GRC weighs 20 kg/m². GRC components are considered lightweight elements by virtue of their thin section. Low-density versions of the material are also possible.

The significance of density, however, goes beyond the simple concept of weight. Density is a good indicator of material quality, a high density meaning slightly greater fibre volume fraction but, more significantly, indicating well compacted, well made material of correct water /cement ratio. The more useful figure is the dry bulk density, and the normal values for good quality materials are:

Spray dewatered	2.02–2.05 t/m ³
Hand spray	1.9–2.1 t/m ³
Vibration cast premix	1.9–2.0 t/m ³

7.18 WATER ABSORPTION AND APPARENT POROSITY

Water absorption and apparent porosity of GRC are determined as part of the routine Quality Control measurement of wet and dry bulk density. Typical values for hand-sprayed GRC with a 0.5:1 sand:cement ratio are:

Water absorption	12%
Apparent porosity	24%

It will be noted that these figures are higher than those for typical concretes, which would normally exhibit a water absorption less than 10%. This is a direct result of the higher cement content in GRC. The permeability of the GRC, as discussed earlier, is, however, significantly lower than that of concrete.

7.19 POTABLE WATER APPROVAL

GRC samples have been tested by the National Water Council (UK) and classified under the heading *Items which have passed full tests of effect on water quality*. This indicates that drinking water may be passed through or stored in GRC without harmful effect, but official approval is given only for specific formulations.

7.20 ULTRA VIOLET LIGHT

GRC is not susceptible to degradation arising from exposure to ultraviolet light.

7.21 NUCLEAR RADIATION

The mechanical properties of samples of GRC subjected to gamma radiation at a dosage rate of 1.2 mega rads/24 hours over a period of 7 days were unaffected.

7.22 FIRE PERFORMANCE

The use of a building material is governed largely by its performance in a range of standard fire tests. These standard fire tests can be divided into two categories:

- Those which test the materials themselves
- Those which test the performance of a particular structure.

The exact nature of the standard test depends upon the country concerned but most tests are broadly comparable with the British Standard fire tests currently used by specifying bodies in the UK.

Table 7.2 gives the performance of GRC to the relevant sections of BS 476 *Fire Tests on Building Materials and Structures*. Relevant Australian fire tests should conform to AS 1530.4:2005 *Methods for fire tests on building materials, components and structures - Fire-resistance test of elements of construction*.

7.22

Table 7.2 Example of the performance of GRC in fire tests

Construction	Non-combustibility BS 476 Part 4	Ignitability BS 476 Part 5	Fire propagation BS 476 Part 6	Surface spread of flame BS 476 Part 7	Stability	Integrity	Insulation
Single skin, standard GRC, 10-15 mm thick	Non-combustible	P	Class 0 ¹	Class 1, zero spread	-	-	-
Single skin, cement/PFA/air entrained GRC ² , 8-15 mm thick	Non-combustible	P	Class 0	Class 1, zero spread	2 hour	2 hour	-
Single skin, cement/perlite GRC ³ , 8-15 mm thick	Non-combustible	P	Class 0	Class 1, zero spread	2 hour	2 hour	-
Single skin, standard GRC and fire insulant ⁴	Non-combustible	P	Class 0	Class 1	1 hour	1 hour	-
Sandwich panel, double-skin GRC enclosing 50 mm glass or mineral wool (min. 30 kg/m ²) ⁵	Non-combustible	P	Class 0	Class 1, zero spread	1 hour	1 hour	-
Sandwich panel, 10-mm GRC/ 50-mm PBA concrete ⁶ / 10-mm GRC	-	P	Class 0	Class 1, zero spread	2 hour	2 hour	2 hour ⁷
Sandwich panel, 10-mm GRC/ 100-mm PBA concrete ⁶ / 10-mm GRC	-	P	Class 0	Class 1, zero spread	4 hour	4 hour	4 hour ⁷

NOTES: ¹ Class 0 rating can also be obtained with a wide range of organic based surface coatings.

² A specially-formulated matrix for added fire protection.

³ A low-density product designed for ease of on-site cutting and drilling.

⁴ Actual degree of resistance depends on the thickness and type of insulant.

⁵ This type of construction will not act as a sandwich.

⁶ Polystyrene bead aggregate concrete.

⁷ Determines the fire rating of the construction.

In the UK the fire resistance of a given structure is defined by its performance in the BS 476 Part 8:1972 test. This test has three criteria. The relevant Australian Standard is AS 1530.4.

Stability The structure under test must not collapse.

Integrity Flames must not penetrate the structure.

Insulation The temperature on the protected side of the structure must not rise by an average of more than 140°C above the initial temperature.

A single skin of GRC will not satisfy the Insulation criterion and the standard cement/sand mix cannot be relied on to maintain Integrity. To guarantee Integrity in single-skin form it is necessary to use a cement/PFA/air entrainment mix, a low-density perlite/cement mix or similar mix with reduced density and increased porosity.

The cement/PFA/air entrainment mix is used only for internal applications at present. A single skin of GRC can provide a 1-hour fire resistance to all three criteria if a suitable thickness of a fire resistant insulant, such as vermiculite/cement or gypsum is applied to the GRC.

Sandwich panels containing a lightweight polystyrene-based-aggregate-concrete (PBAC) core perform well in the fire resistance test. All three criteria are readily achieved with ratings of up to 4 hours. **Table 7.2** indicates the constructions which can be used to achieve different fire ratings. It must be noted that the BS 476 Part 8:1972 test applies to the whole construction under test and, therefore, in the case of a panel, the joint and the fixing points are also tested.

Smoke Production

There is, at present, no Australian, British or ISO Standard test for the smoke production of building materials.

GRC has been subjected to the AMINCO – National Bureau of Standards – Smoke Density Chamber Test.

Thermal Exposure Test Result:

	Flaming	Non-flaming
Average maximum value of specific optical density	4	4
Obscuration time (mins)	Not reached	Not reached

For comparison, timber products usually have *maximum values of specific optical density* of the region of 150 (flaming) and 300 (non flaming) with an *obscuration time* of 2 to 8 minutes; polyester resin products have *maximum values of specific optical density* in the region of 400 and an *obscuration time* in the region of 1 to 5 minutes. GRC, therefore, has negligible smoke production.

Certification

GRC is classified as *Class 0* according to Section E15 of the 1976 Building Regulations (UK).

GRC is listed as an *Approved Lining Material* in Schedule 8 of the Fire Offices' Committee Rules (1978)

GRC meets the requirements for non-combustibility as specified in ASTM E136–73 *Non-combustibility for Elementary Materials*.

Note: Refer also to *American Fire Test Data* prepared by ICBO Evaluation Service Inc. Report No. 4359. It should be noted that a steel stud frame system can achieve a 2-hour fire rating.

Referenced Documents

The following documents were referred to in Chapter 7, in order of appearance:

- BS EN 1170.1:1998 *Precast Concrete Products - Test Method For Glass-fibre Reinforced Cement - Measuring The Consistency of the Matrix 'Slump Test' Method.*
- BS 3177:1958 *Method of Determining the Permeability to Water Vapour of Flexible Sheet Materials for Packaging.*
- ASTM C418–90.
- BS 476 *Fire tests on Building Materials and Structures.*
- AS 1530.4:2005 *Methods for fire tests on building materials, components and structures - Fire-resistance test of elements of construction.*
- ASTM E136–73 *Non-Combustibility for Elementary Materials.*

8 DESIGN REQUIREMENTS and PROCEDURES

8.1 GENERAL

GRC has always been considered a quasi structural material. The use of the material in an application where human safety is involved should be considered in the context of the short-term and long-term, and designed accordingly. Load combinations for various limit states should be according to AS 1170.1 *Dead and Live Loads*.

8.2 LIMIT STATE REQUIREMENTS

8.2.1 Stability Limit State

Every GRC element should be designed to resist overturning, uplift and sliding under the action of the appropriate load combinations.

8.2.2 Ultimate Limit State

All GRC elements should be designed to withstand ultimate limit-state forces, including temporary loads during construction.

8.2.3 Serviceability Limit States

The serviceability limit states of excessive vibration should be taken into account where relevant.

8.3 ADDITIONAL DESIGN REQUIREMENTS

8.3.1 Durability Requirements

GRC members should be designed to:

- have sufficient durability to prevent the relevant limit states from being reached without the need for excessive maintenance, during the intended life of the structure; and
- resist any specific environmental effect which might apply, including extremes of temperature, aggressive atmospheric conditions, liquids and soils.

The single most important design criteria of GRC is the consideration of temperature changes and moisture-induced movement. The prediction of behaviour requires consideration of curing sequences used, moisture content of GRC, coatings of GRC and environmental conditions. The engineer and manufacturer must establish the initial and in-service shrinkage characteristics of the material (likely to be between 0.75–1.5 mm/m) and combine them with the other factors mentioned above.

As a guide, assuming good curing with no coating.

Case 1:

Sound curing, no long-term coating.
Manufacture assumed at approximately 10°C.
Assume 50% theoretical shrinkage occurs during manufacture.

In-service movement will be:

Extreme negative movement (shortening).
Further 50% shrinkage + 10°C temperature shortening (in cold climates increase to 20°C, ie -10°C).
Positive movement (growth).
20% moisture gain over the level of ex-manufacture (70% regain of moisture from the dry state) + 20 to 30°C temperature gain (depending on colour and location).

Case 2:

Sound Curing.

Internal moisture stabilised at 5–15% with impervious coatings on each face. Assume 50% theoretical shrinkage occurs in manufacture.

In-service movement will be:

Negative movement (shortening).
Further 25% shrinkage + 10°C temperature shortening (in cold climates increases to 20°C, ie -10°C).
Positive movement (growth).
0% moisture movement from the level ex-manufacture (25% regain of moisture from its previous state) +20 to 30°C temperature gain (depending on colour and location).

8.3.2 Fatigue Requirements

The effects of repeated loadings, if present, should be considered and, if significant, taken into account in the design.

8.3.3 Progressive Collapse

Consideration should be given to the prevention of progressive collapse so that failure of a single element would involve no more than the loss of that element.

8.3.4 Special Performance Requirements

Elements should be designed to comply with any special performance requirements that are related to its intended use.

8.3.5 Stresses During Manufacture

The engineer should consider the theoretical level of stress induced in the product during manufacture. Further, he should consider Quality Assurance and Management organisational skills of the manufacturer. He may find it prudent to consider the induced stresses as part of a long-term loading combination.

Alternatively, when manufacture has been proven to have proceeded in accordance with nominated method statements, then original design assumptions should be assessed, allowing for early stressing within the overall long-term limit-state condition.

8.4 DESIGN PROCEDURES

Elements should be designed in accordance with loading requirements of Clause 8.5. Further, prototype testing should be utilised to clarify design assumptions, particularly where induced stresses are a hybrid of tension and bending. Also, it should be utilised to establish strength levels for integral GRC ribs whose structural efficiency is very much a function of the compaction achieved.

8.5 LOAD COMBINATIONS

8.5.1 General

The combinations as laid down in AS 1170 Part 1 should be adopted with particular attention to Table 5.2 of AS 1170. Where GRC is used as a cladding with a variety of different coatings and colours, the designer should pay particular attention to surface temperature rather than ambient temperature.

8.5.2 Dead and Live Loads

Load factors reflect confidence in the designated numerical value rather than a hidden agenda regarding strength.

8.5.3 Manufacturing Loads

Excessive loading applied to GRC at an early age is likely to cause microcracking, with increased long-term creep/loss of strength at the cement/sand matrix interface. It is recommended that manufacturing loads are given their appropriate load factors for dead and live loads, unless the engineer can establish that such stresses are not influencing long-term performance.

8.5.4 Temperature and Shrinkage Loads

The extreme predicted temperature and shrinkage criteria should be established for a given design application and a load factor of 1.0 applied. If a normal working life temperature and shrinkage is established, this figure should not normally exceed 0.66 x ultimate limit state.

8.5.5 Temperature and Shrinkage in Combination with Wind Loads

It is not possible to induce ultimate state wind loading at the same time as having ultimate temperature and shrinkage stresses being induced. The application should be examined and the worst combination assessed. If in doubt, the maximum wind or temperature and shrinkage + 50% of second load case should be taken. AS 1170 applies a load factor of 1.25 to temperature and shrinkage. This may or may not be a relevant figure, depending on the extremes of conditions assumed in the analysis. If the extreme is the extreme, use factor 1.0.

8.6 STRENGTH OF GRC

8.6.1 Design Principle

As with any material, there are applications appropriate for GRC and some which are not, and this judgement must be made in the particular circumstance based on the characteristics of the material. Generally, GRC components can be used in situations where the stresses can be evaluated at realistic safe levels, the resulting component is economic, and the consequences of failure are limited in extent.

Although GRC is a fibre reinforced composite, it is not necessary to use the complex composite analysis techniques required by high performance fibre-reinforced plastics. GRC can be treated as a homogenous isotropic material and the techniques used for the analysis of GRC stresses, strains and deflections are identical to those used with isotropic materials such as metals, provided the stresses are within the elastic limit of the material.

The process of designing a product can be broken down into three basic components:

- Resistance to applied loads. Mechanical design is the most commonly performed part of the design process, but other factors also merit consideration.
- Resistance to environmental influences. Physical design is often neglected, but the analysis of sound and thermal insulation and performance in fire is required for building components and, for GRC products, moisture and thermal movement may exert more influence upon the final solution than the applied loads.
- Installation of the component. The GRC component is often required to interact with some other structure or components and this should always be considered at the design stage.

8.6.2 Mechanical Design

The design of any product has to satisfy many requirements. Adequate strength against the specified loads is an obvious requirement; mechanical design will therefore commonly be performed to ensure satisfactory performance. The loads to which a product may be subjected during demoulding and handling should not be ignored.

This clause covers mechanical design aspects, to give satisfactory performance in relation to the short- and long-term strength properties of GRC.

As with other materials, it is normal practice to design at stresses below the elastic limit. The elastic limits of GRC in compression, bending (LOP), tension (BOP) and shear do not change significantly in most environments, so the initial property values can be used as a reference.

Design stresses are also selected with respect to long-term strength values. With certain types of GRC where there is a reduction of ultimate strength, accelerated ageing tests indicate that the strength stabilises.

8.6

Design stresses should be based on this stable value, and should allow a suitable factor of safety. Certain new GRC mixes using metakaolin do not exhibit the same % drop of strength as those found with traditional spray GRC mixes.

In terms of the bending strength of a good quality hand sprayed GRC, a typical allowable design stress is 6 MPa, which covers both of these requirements.

The high initial ultimate properties of the material are a bonus in the early life of the product, allowing the use of higher design stresses for structures such as permanent formwork, which may require high strength only in the early life of the product.

8.6.3 Identification of Strength of GRC

Since GRC is not one material, but a family of closely related materials, the design stresses to be used will depend on the choice of formulation and manufacturing process. Furthermore, it is influenced by the environment to which it will be subjected. Also, each individual material will have several design stress levels because the material characteristics result in different strengths, dependent upon the type of loading and the section being loaded.

The design stress chosen must also be related to the quality of manufacture.

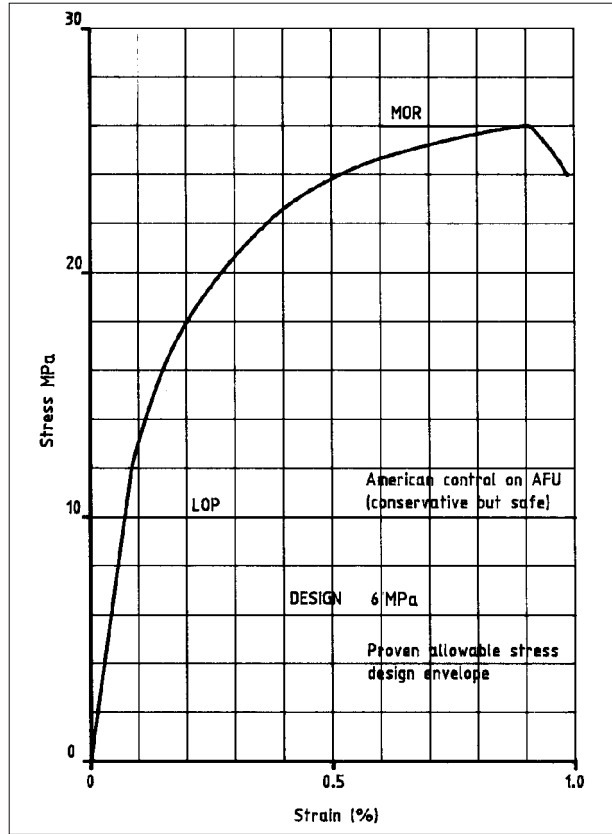


Figure 8.1 Stress/strain curve. Original Pilkington Bros allowable stress recommendations

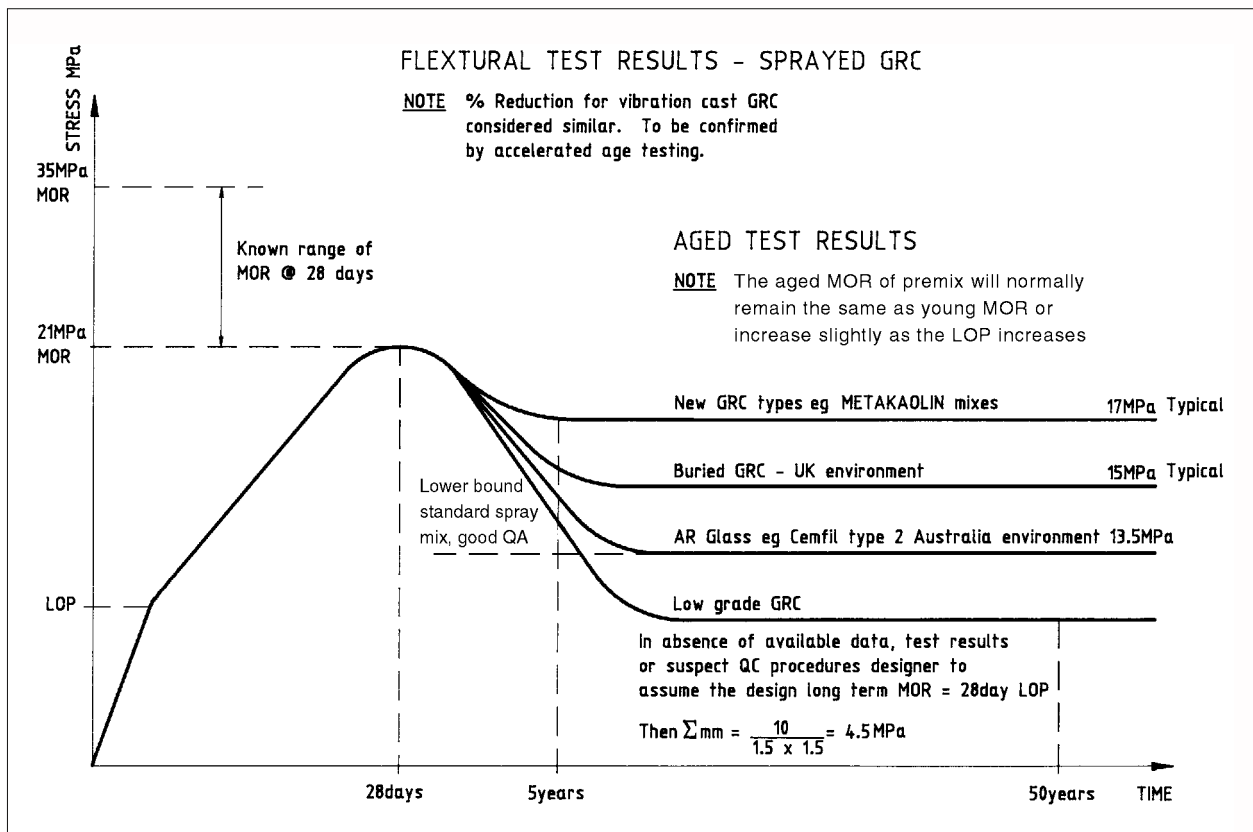


Figure 8.2 Comparison of results for typical GRC mixes

GRC long-term strength should be identified by accelerated age testing. The strength is influenced by five fundamental items:

- Mix design
- Curing
- Long-term coatings
- Environment of application
- Quality control.

In the absence of data, the engineer should use the 'so called' low-grade curve. However, the engineer should identify his appropriate design data curve.

8.6.4 Background

Even with special alkali-resistant glass compositions, if moisture is present for cement hydration, the conventional sprayed GRC composite still loses significant strength and ductility with time. Premix GRC and certain new alternative mixes using metakaolin do not lose strength to the same degree. Two theories have been suggested to explain this phenomenon in GRC composites. The leading theory is that ongoing cement hydration results in products, primarily calcium hydroxide, which penetrate the fibre bundles and fill the interstitial spaces between the glass filaments. This increases the bond of the glass fibre to the cement matrix and leads to a reduction in fibre

pull-out, and, in turn, a reduction in strain to failure and tensile strength with time. This phenomenon is called embrittlement. The second theory is that chemical attack by hydroxyl ions on the surface of the glass fibre may result in a reduction in the strength of the fibre.

Researchers are not fully in agreement as to which of the two mechanisms (embrittlement or chemical attack) is primarily responsible for the observed decrease in GRC strength and ductility. Recent studies suggest that they may occur simultaneously, but at different rates. It should be noted, however, that in dry, indoor environments where cement hydration and chemical attack is slowed significantly, early composite properties are maintained longer.

However, in usual environments, using current portland cements there remain reductions in strength and strain to failure, which must be recognised by the designer and user. The length of time over which these reductions take place, and the degree to which they take place, depend on the type and content of the fibre and polymer, and upon the environment. Tests indicate that the aged ultimate strength of GRC exposed to outdoor natural weathering is at least equal to the yield strength (LOP) at 28 days.

Developments in new AR glass manufacturing techniques, and the use of polymer admixtures have resulted in improved long-term properties, including better retention of strain to failure and strength, compared to earlier formulations.

New cements and formulations are being developed and some are currently in use overseas. With AR glass fibre reinforcement, these systems exhibit very little loss of ductility in the fully aged condition. As this technology develops, it is expected that it will lead to substantial changes in the design and application of GRC.

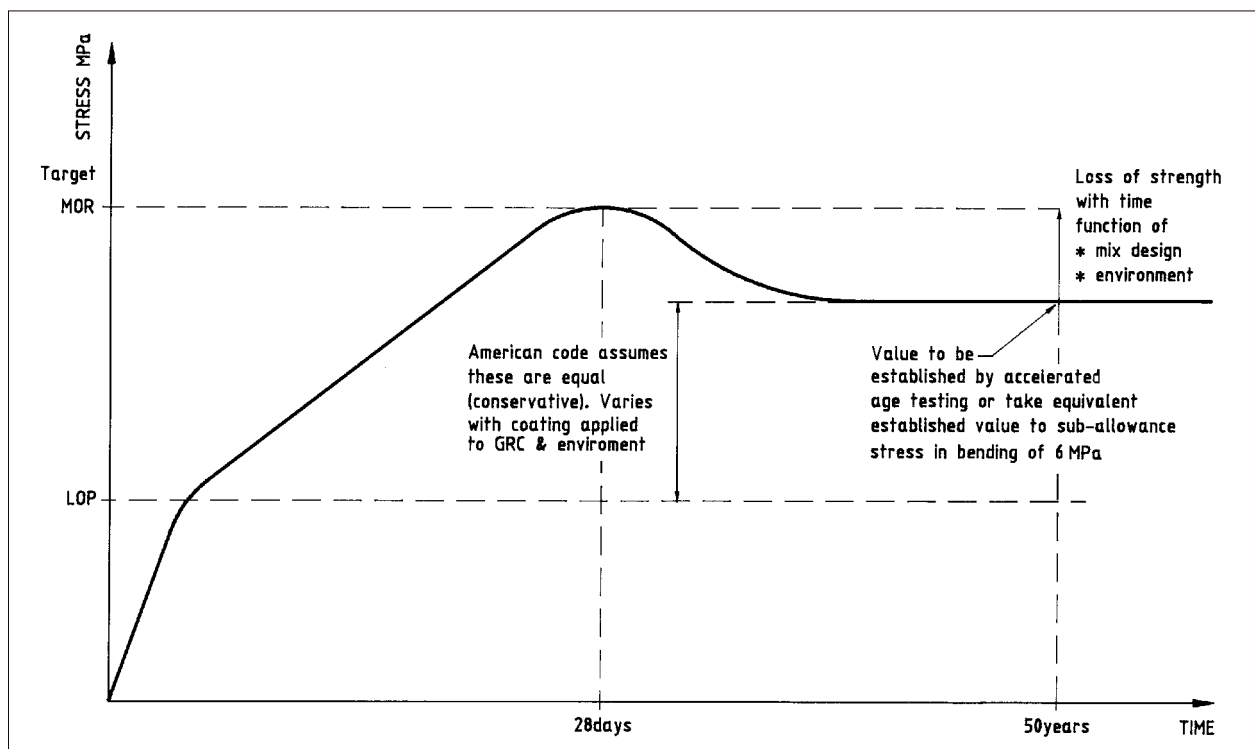


Figure 8.3 GRC loss of strength with time

8.7

Nothing in this publication is intended to limit development and utilisation of these or other improvements in the system. The intent of this publication is to establish

procedures to maintain adequate safety factors that are consistent with the reliability and lifetime properties of GRC and the associated components. These principles should be maintained in the evaluation of new developments and new procedures for their application.

8.6.5 Material Ultimate Factors

Material factor should be:

Bending Stress	= 1.5
Compression Stresses	= 1.0
Tensile Stresses	= 3.0
Interlaminar Shear	= 8.0
In-plane Shear	= 8.0

ie if GRC = 21 MPa MOR – conventional long-term predicted strength (divide by 1.5) = 13.5 MPa (see **Figures 8.2** and **8.3**)

Thus ultimate...

Bending Stress	= 9.0 MPa
Compressive Strength	= 12.0 MPa
Tensile	= 4.5 MPa
Interlaminar Shear	= 1.5 MPa
In-plane Shear	= 1.5 MPa

Design should be related to predicted long-term aged strength in the absence of test data. Long-term estimated figures from original UK research is tried and tested and should be adopted.

New load factors for ultimate states shown above reflect long-term established allowable stress analysis. If manufacturers can prove reduced long-term loss of strength to the design engineer, the design limit of the product can be improved.

For example, if GRC has 21 MPa MOR at 28 days with a working wind load

Loss of strength	= 30%
Material factor	= 1.5
Load factor	= 1.5
$21 \times 0.64 / 1.5 \times 1.5$	= 6 MPa
	= equivalent to original elastic stresses

The designer should compare his derived equivalent allowable stress with the long-term LOP recorded value since world opinion suggests that this figure should be similar. Without exhaustive analysis, it is not recommended that the long-term equivalent allowable stress exceed the aged LOP by more than 25%.

8.6.6 Serviceability Conditions

A serviceability check is required for deflection utilising working load analysis. High-build finishes to GRC may require more-stringent deflection control but generally a limit of $L/350$ has proven to ensure adequate serviceability performance.

8.6.7 Shape Factor

Pure bending is generally accepted to be twice the strength of pure tension. The engineer must identify which stress case is appropriate to a particular part of this design condition and work accordingly.

8.7 IMPORTANT DESIGN CONSIDERATIONS

8.7.1 Polymers

The industry has always felt that the polymer improves 7- and 28-day test results though their long-term effect is questionable. Relating strength to accelerated age testing eliminates the unknown.

However, since it is a wet test this negates much of the advantage of polymer. Unless a dry test can be derived for accelerated ageing the advantage of polymers must be restricted to curing.

8.7.2 Vibration Cast GRC

Products produced by vibration casting are subject to exactly the same quality control procedures as conventional GRC. The most important aspect is to establish strengths for the two principal axes of fibre orientation in order that design assumptions can accommodate the significant variation.

8.7.3 Sandwich Panels

The engineer must assess:

- Consistency of face-skin thickness.
- Compaction and therefore strength and modulus of the two skins – and their respective gains of strength.
- Consistency and strength of GRC.
- Laminar shear strength.
- Early stressing due to lifting.
- Possible variation in gain in strength from day to day due to climatic change and how this affects early stressing.
- Release of core gas and vapour.
- Bowing results of full-scale prototype test of panel subject to alternate wetting and drying to a schedule agreed by the engineer.

Once this data is available, the engineer can produce a design which he can confidently certify as being within good building practice subject to satisfaction of quality assurance procedures.

8.7.4 Integral GRC Ribs for GRC Panels

The engineer must assess:

- Appropriate stress mode to suit shape factor.
- Possible shadowing on face (ghosting) and effect on shrinkage, ie will they induce face wrinkling or overall bow.
- Possible differential stresses which can be set up by the use of preformed ribs on a green face skin.
- Compaction achieved around inserts or over void formers (if used) and how this affects strength.
- Accommodation of stresses due to lifting, monitoring of strength on daily basis at time of lift to ensure the engineers assumptions are valid.
- Variance in colour due to hydration differences with moisture retention.

Once this data is available, the engineer can produce a design which he can confidently certify as being within good building practice subject to satisfaction of quality assurance procedures.

8.7.5 Steel Frame

The use of a steel frame automatically eliminates the need to consider many of the factors listed in Clauses 8.7.3 and 8.7.4 because of the available design redundancy in the support frame.

The engineer must still be aware of important considerations:

- Design of GRC face as a flat two-way plate.
- Orientation of anchors to minimise induced stress.
- Use of gravity anchors to support load and thereby reduce required stiffness of individual anchors and reduce problems of induced stress.
- Stiffness in steel frame to hold panel square during manufacture, transport, curing and erection yet utilise advantages of lightweight section.
- Control of face-skin thickness and setting of frame if face-skin buried anchors are used instead of bonding pads, with particular attention to punching shear.
- Allowance for slippage on anchors.

8.8 MODULUS OF ELASTICITY

In calculating the deflections of GRC elements it should be permissible to use a Young's Modulus value of E of 20×10^3 MPa for sprayed up material and 16×10^3 MPa for premix. Poisson's ratio should be taken as 0.24.

Note: The Young's Modulus value will vary with the mix type and the age of loading. Manufacturers' test data for Young's Modulus of the particular mix type required for the element may be used as an alternative to the above for the purposes of calculating deflections, if approved by the Engineer.

8.9 FLANGED, BOX AND I-SECTIONS

8.9.1 General

Where a GRC skin or plate is assumed to provide the flange of a beam, the skin or plate should be cast integrally with the web such that, the lap of the glass fibres from the web to the flange is adequate to ensure transfer of the longitudinal shearing stresses between the flange and web from the limit states of strength.

8.9.2 Effective Width of Flange for Strength and Serviceability

In the absence of more accurate information, the assumed effective width of the flange should be taken to the strength and serviceability limits states as follows:

- For T-beams and beams having flanges on either side of a web, $b_{ef} = b_w + 0.2 L_o$
- For L-beams and beams having a single flange on one side of a web, $b_{ef} = b_w + 0.1 L_o$

where: b_{ef} = effective width (m)
 b_w = web width (m)
 L_o = span (m)

Note that in both the above cases, the overhanging part of the flange considered effective should not exceed half the clear distance to the next member. The effective width so determined should be taken as constant over the entire span. For continuous beams, L_o may be taken as $0.7L$.

8.10 SIMPLIFIED METHOD FOR TWO-WAY PLATES AND SKINS

8.10.1 General

The design bending moment for the strength limit states of two-way simply-supported or continuous rectangular plates or skins which are supported on four sides may be determined from Clause 7.5.2 provided that:

- the plates or skins are of uniform thickness
- the loads are essentially uniformly distributed.

8.10.2 Design Bending Moments

The maximum design bending moment per unit width, M^* , should be calculated as:

$$M^* = BwL_x^2$$

where: B is given in **Table 8.1**
w is the design load per unit area factored for the strength limit state.

Table 8.1 Bending moment coefficients for rectangular panels, supported on four sides

Edge Condition	Coefficient B for Values of L_y/L_x							
	1.0	1.1	1.2	1.3	1.4	1.5	1.75	2.0
1 Four edges continuous	0.032	0.037	0.042	0.047	0.049	0.053	0.059	0.064
2 One short edge discontinuous	0.037	0.042	0.048	0.051	0.055	0.057	0.063	0.067
3 One long edge discontinuous	0.037	0.047	0.055	0.061	0.067	0.072	0.081	0.088
4 Two adjacent edges discontinuous	0.047	0.055	0.061	0.068	0.073	0.077	0.087	0.093
5 Two short edges discontinuous	0.045	0.051	0.053	0.057	0.060	0.063	0.067	0.071
6 Two long edges discontinuous	0.045	0.046	0.056	0.065	0.072	0.078	0.091	0.100
7 Three edges discontinuous, one long edge continuous	0.057	0.065	0.070	0.076	0.081	0.085	0.092	0.098
8 Three edges discontinuous, one short edge continuous	0.057	0.057	0.064	0.072	0.078	0.084	0.096	0.105
9 Four edges discontinuous	0.056	0.066	0.074	0.081	0.087	0.093	0.103	0.111

8.11 SANDWICH BEAMS

The analysis of sandwich beams is slightly more complex than for normal beams, since the thickness of the relatively low modulus core material used allows an extra amount of deflection.

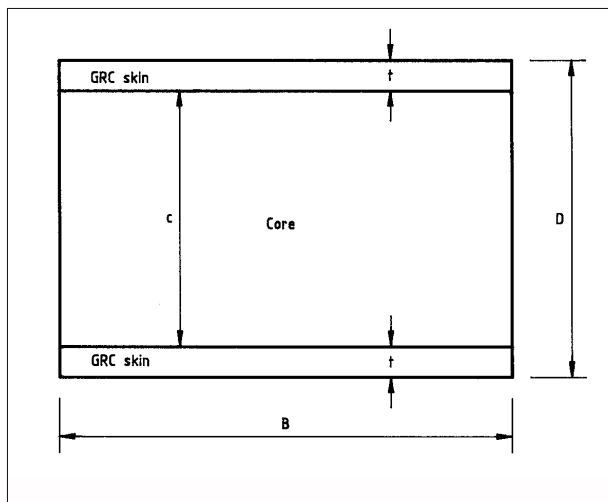


Figure 8.4 Sectional area of sandwich panel

$$\text{Stress, } f = \frac{WL}{k_1 Z}$$

$$\text{Deflection, } y = \frac{WL^3}{k_2 EI} + \frac{WLc}{k_1 BD^2 G}$$

where: $Z = Bct$

$$I = \frac{BctD}{2}$$

G = shear modulus of the core

Values k_1 and k_2 from **Table 8.2**

Table 8.2 Values of k_1 and k_2 for use in stress and deflection calculations for sandwich beams

Load type	Support condition	Loading diagram	k_1	k_2
Point load	Cantilever		1.0	3
Uniform	Cantilever		2.0	8
Hydrostatic	Cantilever		3.0	15
Point load	End supports		4.0	48
Uniform	End supports		8.0	77
Hydrostatic	End supports		7.8	77

This formula for deflection takes no account of the side walls which are usually built into a GRC sandwich structure. Hence, the deflection calculated will be an overestimate. An alternative method of calculation assumes the beam to have a width, B , and length, L , but only part of the width B is effective. As an approximation, the effective width, B_e , is given by:

$$\frac{B_e}{B} = 1 - \frac{0.6B}{L} \quad (\text{assuming } L \geq B)$$

The sandwich beam can now be designed as a box section of width B_e and the deflection calculated accordingly.

Sandwich structures should also be checked for the shear load transmitted through the core material. The shear force, V , can normally be taken to be equal to the maximum support load (in newtons) and the shear stress is then:

$$f_s = \frac{V}{Bc}$$

which should be less than 40% of the core shear strength.

Table 8.3 Shear modulus and shear strengths for PBAC and high density foams

Core Material	Shear modulus (MPa)	Shear strength (MPa)
Polystyrene-bead-aggregate concrete ¹ (Styropor), 400 kg/m ³	230.0	0.34
High-density polystyrene, 25 kg/m ³	11.0	0.26
Polyurethane foam, 40 kg/m ³	2.3	0.32

Notes: ¹ The figures for PBAC are dependent upon the quality.

Table 8.3 gives shear modulus and shear strength for PBAC (Styropor) and high-density foams.

Selection of plastic foams as core materials will depend on operating conditions and the temperature stability of the foam. Polystyrene foam appears to work satisfactorily with sandwich panel surface temperatures up to about 80°C, and polyurethane foam has a superior resistance to high temperatures.

Design of sandwich structures assumes that the shear strength of the bond between the various layers of the sandwich is also greater than the shear stress. If this is not the case, the structure ceases to act as a sandwich and may be overstressed. The shear attachment can take other forms including the use of GRC webs joining the two skins, and these should be designed so that the web shear stress is less than the web design stress.

Experience has shown that it may be advisable to limit the area of sandwich structures to a maximum of 6.5 m² (approximately 3.6 m x 1.8 m). Although there is no justification for this from analysis of mechanical strength, it is apparent that more problems are experienced in production, handling, installation and use with sandwich structures larger than 6.5 m² in area, unless the manufacturing process and installation procedures are specifically developed to overcome these problems.

8.12 THERMAL EXPANSION

Thermal dimension changes in GRC can be calculated from the formula:

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

where: α = coefficient of thermal expansion

ΔT = change in temperature

L = length over which the dimension change is measured

ΔL = change in length

Hence, for a 2-m-long GRC component undergoing a temperature rise of 30°C

$$\Delta L = 20 \times 10^{-6} \times 30 \times 2000 = 1.2 \text{ mm}$$

(assuming a coefficient of thermal expansion of $20 \times 10^{-6}/^\circ\text{C}$)

Surface temperature measurements in the UK indicate surface temperature values of 10–60°C for light-coloured surfaces to 80°C for dark surfaces over a period of one year. It is clearly evident that substantial expansion or contraction can occur.

8.13 STRESS DUE TO TEMPERATURE AND SHRINKAGE

Traditionally, assessment of the bow of a product due to both temperature and shrinkage is attempted. It is normally impossible to separate the two. It is recommended an approach similar to Fordyce and Wodehouse be used (reference 2).

Having assessed the bow, a hypothetical load is applied to create the bow and thus assess the stress. This is using “external work” to assess internal stress. Whilst identical answers would be expected, it is suggested that the product be modelled as an equivalent truss to reflect where tension or compression will be generated under movement. Then one set of members should be given an induced increase or reduction in length to reflect the induced condition. Generated stresses are much less than by external load modelling. It may be noted that the established rule of thumb of allowing 1–1.5 MPa for temperature and shrinkage is valid in lieu of more-detailed subsequent investigation.

The value of the deflection expected in a flat sandwich component that is free to bow is given in **Figure 8.5**.

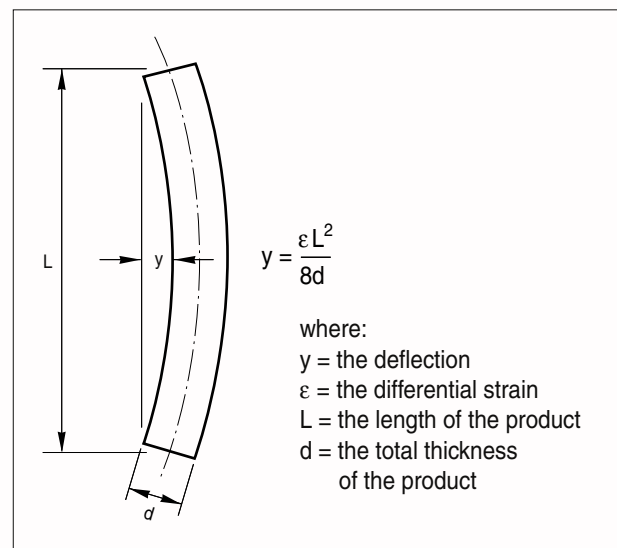


Figure 8.5 The relationship between bowing deflection and panel dimensions

8.14

AS 3600 suggests that a limit on deflection of $L/350$ is suitable for cladding panel design purposes. Applying this to the case of a GRC sandwich cladding panel with $\epsilon = 0.08\%$ (a value obtained from inspection of many contracts in the UK) results in the requirement for $d > 0.035L$. This thickness is generally greater than that required for resistance to normal cladding loads.

If a sandwich panel is prevented from deflecting, either by intermediate or continuous fixing of a flat sandwich, or by the inherent resistance of certain shaped sandwich constructions to deforming in particular directions, then restraint of the differential strains will induce stresses in the GRC skins.

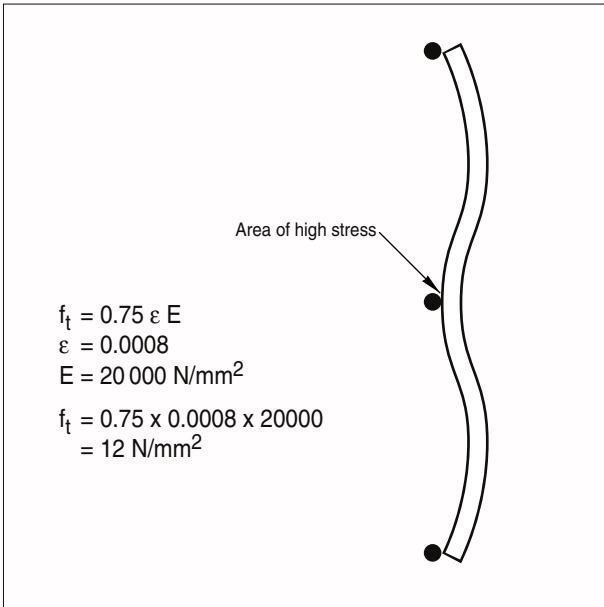


Figure 8.6 The effect of intermediate restraint of the bowing deflection

On the other hand, in the case of flat panels significant stresses are not produced provided that the panel is allowed to move and deflect freely (Figure 8.7). This dictates the avoidance of intermediate fixings and strongly suggests the use of fixings that allow for bowing and shrinkage movement. Fixings should allow freedom of movement.

Whilst significant skin stresses do not normally occur in simple flat sandwich panels that are free to move, in detail there can be stresses of greater magnitude where particular adverse strain gradients apply in conjunction with a rigid core material. Consideration should be given to this aspect and in the absence of detailed calculations it may be appropriate to include an allowance of 1 MPa for residual shrinkage stresses.

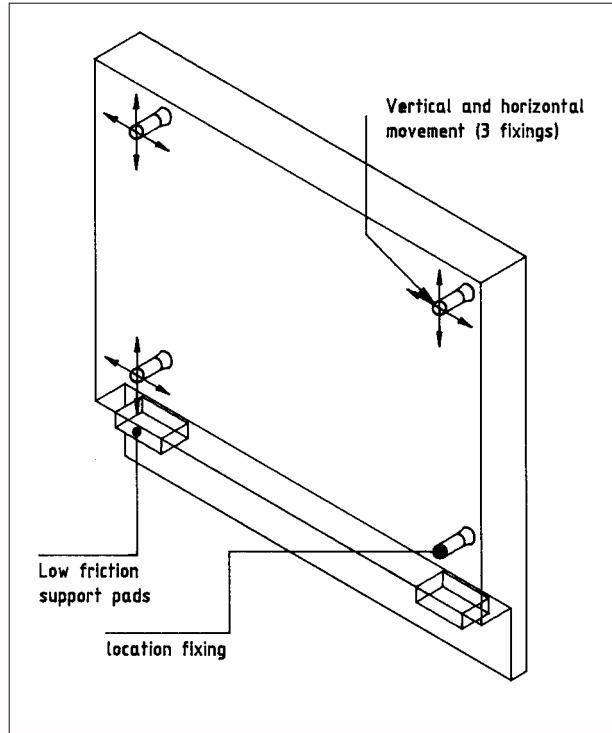


Figure 8.7 Fixings to allow freedom of movement

Sandwich panels that are either shaped or curved (Figure 8.8) can be subject to tensile stresses irrespective of fixing condition. This is of particular significance in climates where variable weather conditions are prevalent. In such locations, shaped sandwich panels should not be used. In these cases, the panel shape should be simplified or single-skin construction adopted. Where a shaped sandwich panel has sufficient bending stiffness to induce high stresses it will often have enough strength to be designed as a single skin. This may be the preferred solution.

8.14 ALLOWANCE FOR MOVEMENT AND FIXINGS

In addition to providing allowance for movement and fixing positions, the detailing of the areas of a structure surrounding a GRC component should ensure that movement of the GRC is not restrained. A typical example of restraint is provided by screeding a floor directly up to the back of a cladding panel, which may not only prevent the natural bowing, but may also lock fixings which are otherwise designed to allow movement, Figure 8.9.

The presence of other members which may restrain movement should also be considered, and steps taken to ensure that restraint does not occur.

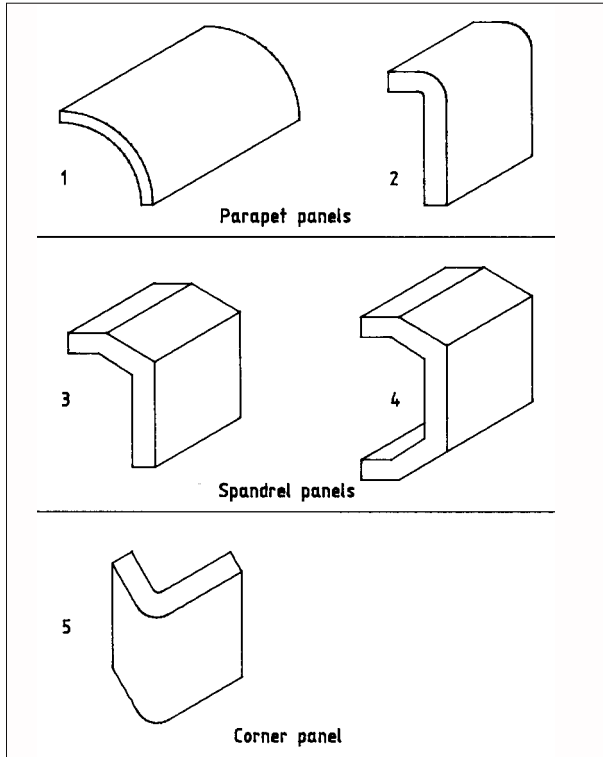


Figure 8.8 Examples of shaped panels where it is recommended that single-skin construction is used

8.15 DEFLECTION

Panels should have adequate stiffness to limit deflections or any deformations that may affect handling, serviceability or induce cracking.

Deflections due to service loads are frequently limited to $1/240$ of the span, but may need to be less in some conditions.

8.16 SHEAR AND TENSION

Direct shear seldom controls the design of GRC panels. Interlaminar shear likewise seldom controls the design of flat GRC elements unless the span/depth ratio is less than 16. However, interlaminar shear may control design of connections and, whilst in-plane shear occurring in the diaphragms and webs seldom controls design, it should be considered and the principal tensile stresses limited. The tensile strength of GRC is less than the flexural strength. Due to impracticality of tests to determine tensile strength on a specific job basis, it should be assumed to be 50% of the flexural strength.

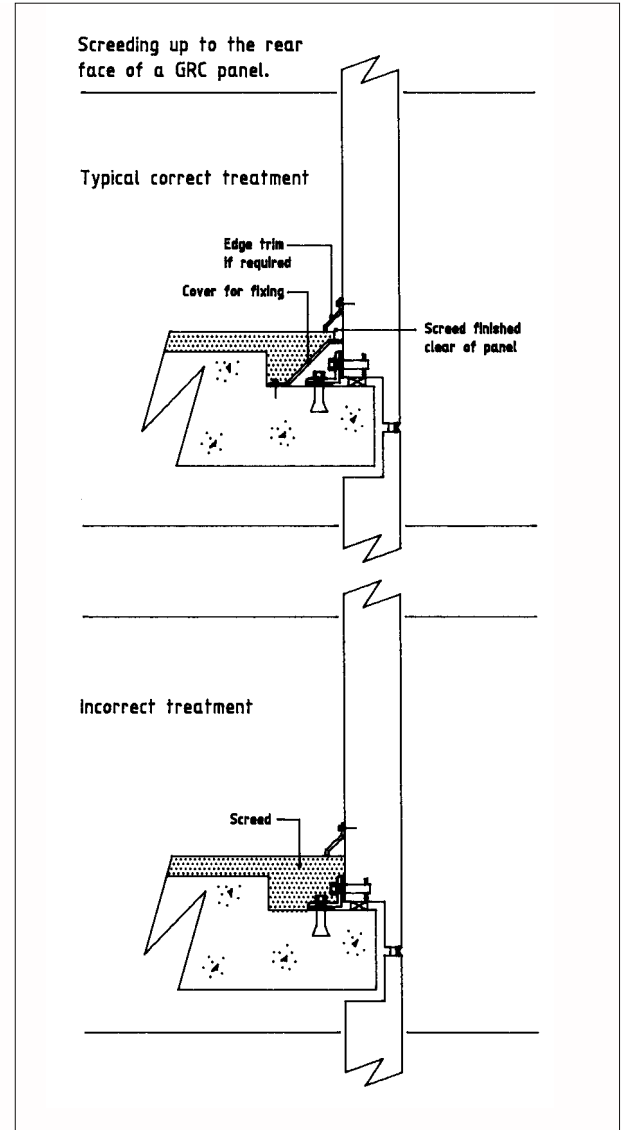


Figure 8.9 Interface treatment; floor screed to panel

8.17 FACADE PANEL LAYOUTS

Designers are encouraged to use steel stud framing. The rules shown here for steel are relevant throughout. When possible, it is desirable to have windows or other openings occurring entirely within one panel to minimise fit and joint-sealing concerns. For large openings, panels should be configured so that openings are least affected

by movement of the structure. The panel configurations in **Figures 8.10(a)** and **8.10(c)** are undesirable layouts for openings. **Figures 8.10(b)** and **8.10(d)** show acceptable layouts for openings.

Panel layouts must be coordinated with the connections to the structure so storey drift is not in conflict with panel jointing. Generally, this is best facilitated if horizontal

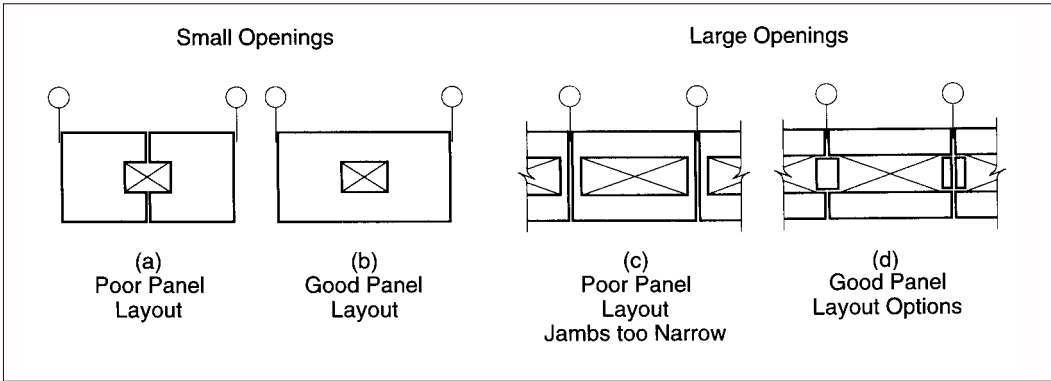


Figure 8.10 Panel joint/opening configurations

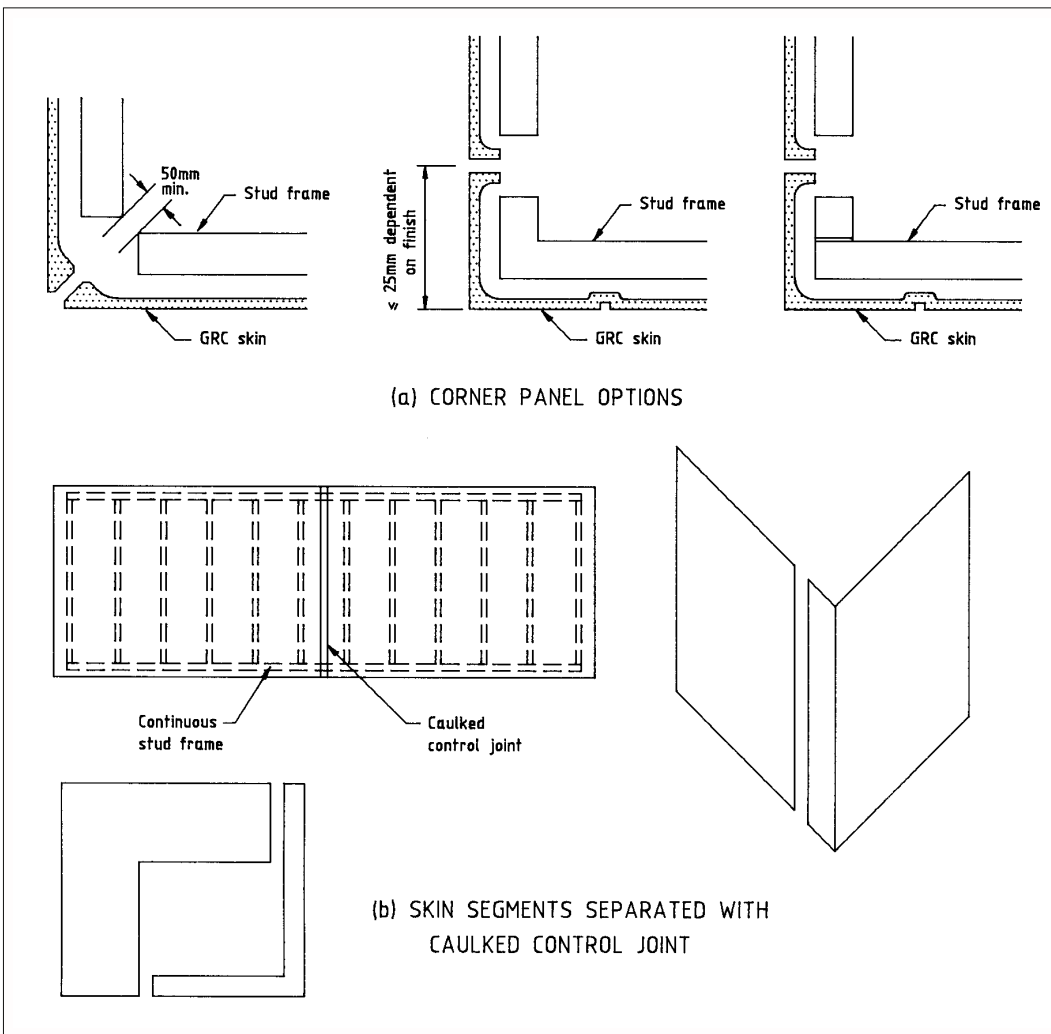


Figure 8.11 Corner panel options/caulked control joints

joints are continuous, as in **Figure 8.10(d)**. If a continuous column cover effect is desired, it may be advisable to simulate it with the panel shape and false joints.

The panel manufacturer should be consulted for panel size. For long panels (over 6 m) it may be necessary to segment the skin with caulked control joints as in **Figure 8.11** to facilitate movement of the skin. Sometimes, panel returns, or other shapes, are detached from the main skin as in **Figure 8.11** to limit differential volume-change stresses. Each skin segment may require its own gravity anchors, but often more than one skin segment is attached to a single large stud frame.

Resulting from the spray-up method used to manufacture GRC panels, integral returns should generally be less than 500 mm.

Since circumstances vary, the manufacturer should be consulted for limits to prevent the fresh GRC from sagging at vertical surfaces in the mould. See **Figure 8.11**.

8.18 STUD FRAME SYSTEM

The stud frame system is by far the most common type of panel in use today. Because of its appeal and ability to adapt to many conditions, it is given greater coverage in this publication.

The system consists of four distinct parts; the panel skin (which may include an architectural facing), the anchors that attach the skin to the stud frame, the stud frame itself, and the connectors that attach the stud frame to the structure. The anchors are intended to be flexible in the plane of the panel (except when carrying gravity load) so that they provide minimum restraint against the volume change of the skin. They must of course, transmit wind loads to the stud frame. The stud frame must accumulate all the loads and transfer them to the structure via the connections. With this system, the skin is never attached directly to the main building structure.

All loads must have a positive path from their origin to the main building structure. **Figures 8.12** and **8.13** show some of the more common methods. For discussion purposes, spandrel panels are shown in these figures; but the concepts apply to other applications as well, even though the detail may differ. In all cases, the wind load is transferred from the skin to the studs (or other frame members) by the flex anchors, by the studs to the upper

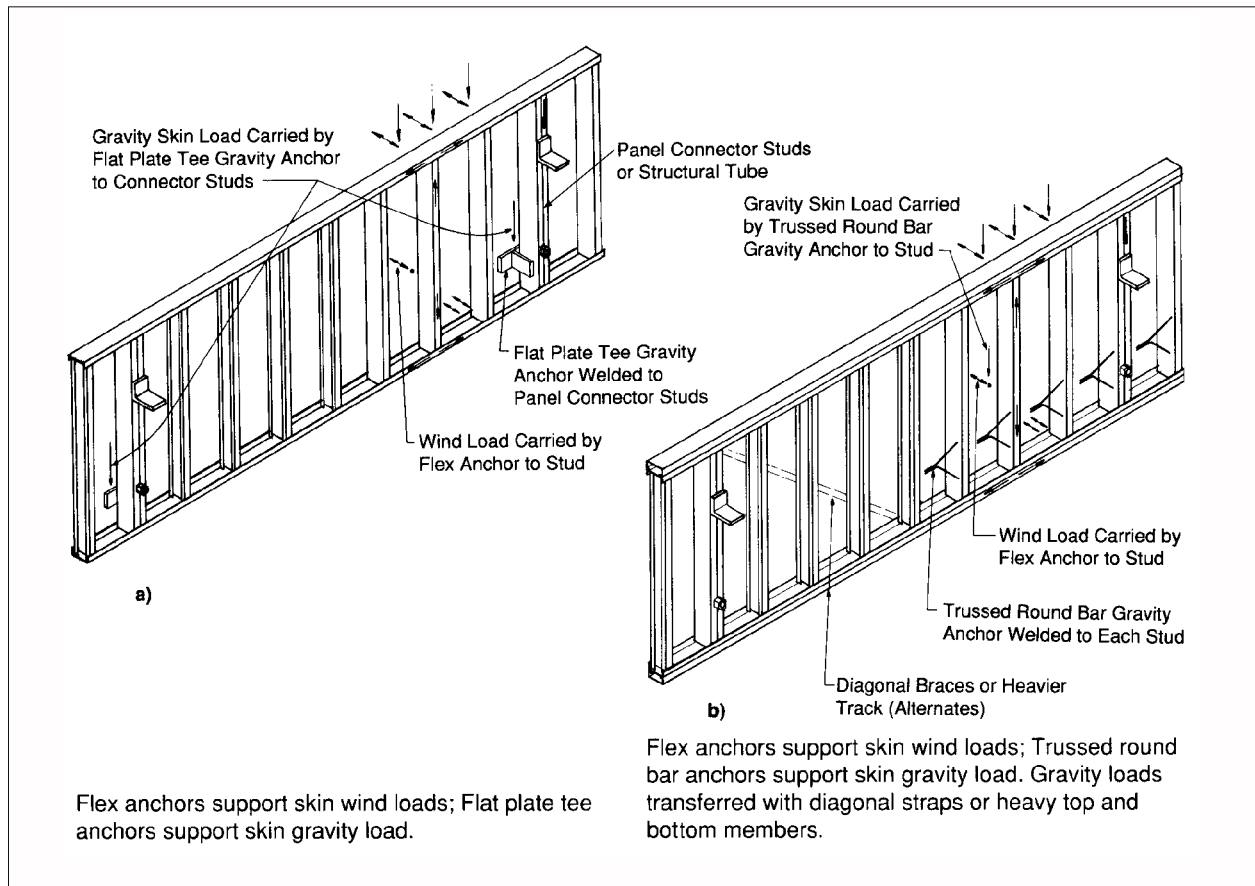


Figure 8.12 Optional gravity anchor and panel framing systems

8.19

and lower tracks, by the tracks to the load of the skin to the frame. **Figure 8.13** is only for small panels where the flex anchors can be stiff enough to carry the gravity load without being so rigid that they unduly restrain the skin against in-plane volume changes. **Figures 8.12** and **8.13** have the gravity loads distributed to the stud frame uniformly along its length. This requires the frame to have sufficient in-plane rigidity to pick up the load and transfer it to the connection system. In **Figure 8.13** the gravity anchors transfer the weight of the skin to the stud frame at two discrete points. Alternatively, the load can be carried by multi-anchor systems as long as the load path is clearly identified. It should not simply be assumed to be carried on them all. If these points are at the connector studs (or tubes), the rest of the frame has little participation in the gravity-load transfer.

8.19 SKIN DESIGN

If the skin has an architectural facing that has volume-change characteristics that are not equal to the GRC backing, the differential stress can be very high. This must be assessed.

Typically, facings are not reinforced with glass fibre so they are not considered as contributing to the strength of the skin.

The design of the skin for wind load is straightforward. The panel skin spans between the anchors. It can be modelled as a simple or continuous beam on a row of

flex anchors, or as a two-way slab system, with the bonding pads acting similar to a column capital. Consideration should be given to non-typical anchor spacing and edge conditions, as they will affect skin load capacity. Variable stiffness of the members within the stud frame should be considered, as it could result in their carrying load that is disproportionate to their tributary area, which may have an effect on the skin design. The highest wind load is often suction. At corners, eddy currents may create a negative pressure on one face while the other face has positive pressure.

Panels with deep returns and integral rib or sandwich panels should be investigated for the effect of sun or rain on one surface and not the other. Experience has shown, however, that rigorous mathematical modelling of potential moisture or thermal volume changes may typically lead to calculated stresses significantly larger than the limiting stress of GRC and that empirical designs are often used. In some cases, mitigation of potential stress may lead to detachment of the return with control joints.

Panel shapes can be such that the self weight above or below the gravity anchors could create high flexural stresses. Even with low stress, creep could in time distort the panel. **Figure 8.14** shows some examples where this is controlled with 'C' shaped bars similar to flex anchors. **Figure 8.15** indicates a method of reducing restraint while still providing load capacity at returns.

Analysis of the skin must consider all sources of stress with

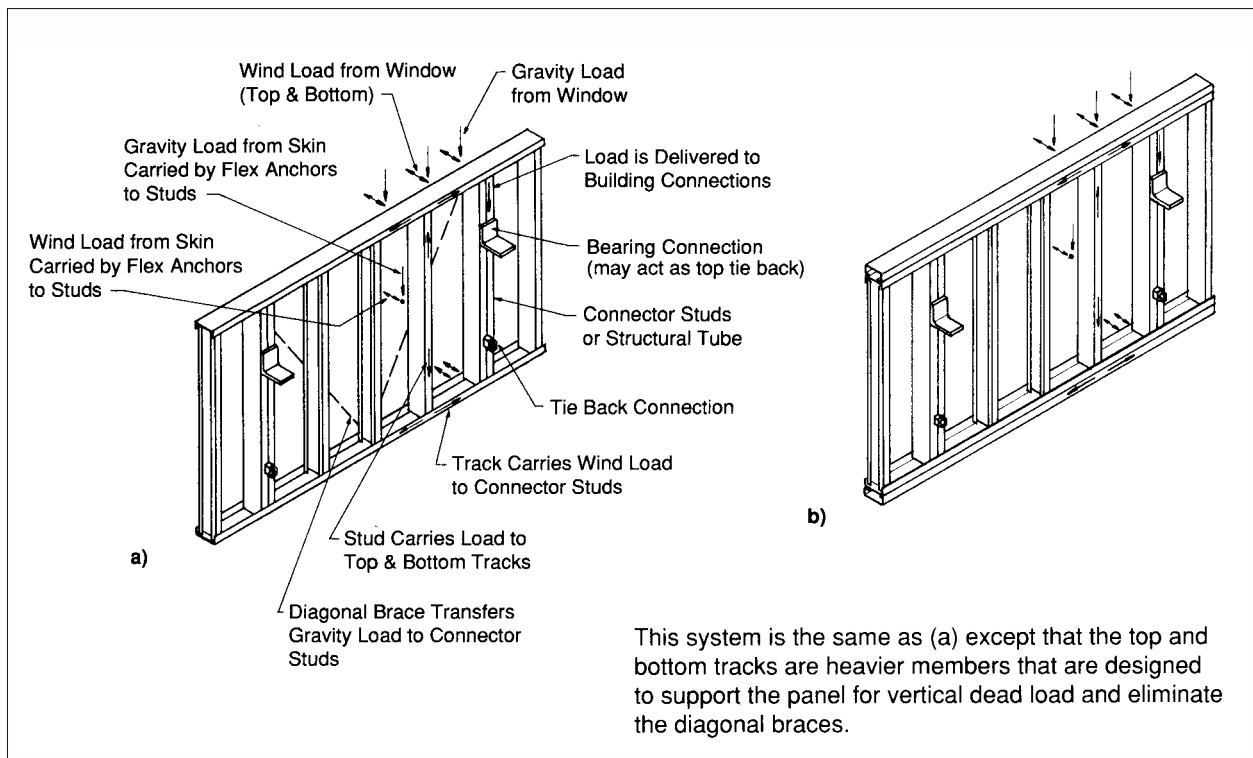


Figure 8.13 Optional method of stiffening frame for panels without gravity anchors – (small panels only)

the appropriate factored load combinations from Clause 8.5.1. Some of these stresses will be flexural and some will be axial. Since the tensile strength is smaller than the flexural strength, and since different loads use different load factors, stresses can not be added directly.

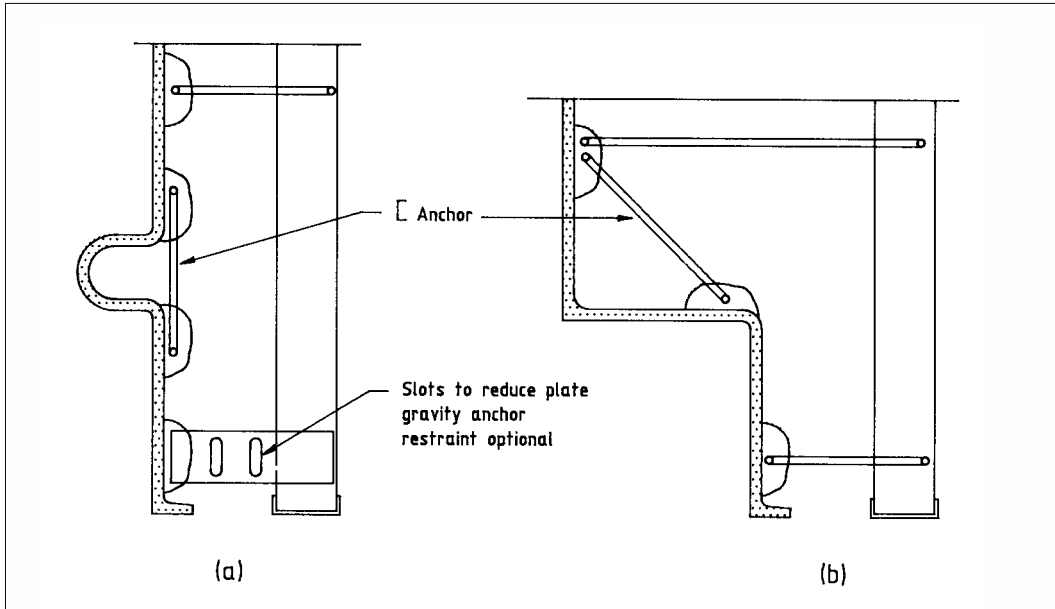


Figure 8.14 Possible anchor arrangement for dead load skin stress reduction

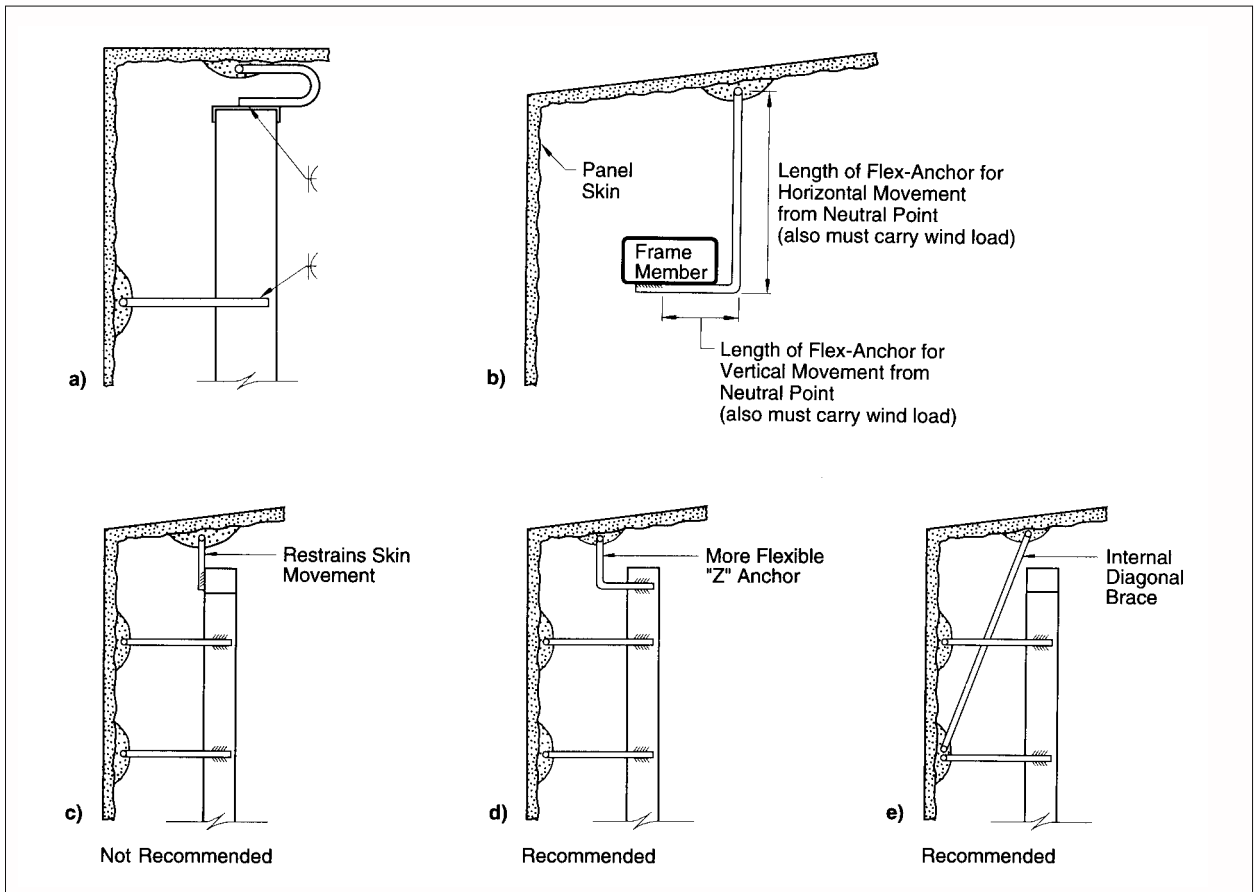


Figure 8.15 Flex anchor variations to reduce restraint

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8.20 ANCHORAGE OF PANEL SKINS TO STUD FRAME

It is imperative that the anchorage of the skin to the stud frame be accomplished in such a manner as to minimise restraint of the in-plane volume changes of the skin. Each anchor should be examined for its action in all three axes; perpendicular to the skin, in-plane vertical and in-plane horizontal. Typically, all anchors carry wind and perpendicular seismic loads, so they are rigid on the axis perpendicular to the skin. Gravity anchors carry load vertically, but are flexible to allow in-plane horizontal movement. Seismic anchors carry in-plane horizontal forces, but should provide minimum vertical restraints.

Volume-change movement of the skin is usually considered to be zero at its centre and to increase in proportion to the distance from this 'neutral' point.

The skin should not act, or be assumed to act, as part of a composite system in conjunction with the stud frame; so horizontal shear capacity of the anchorage system should be kept as low as possible, except as noted above.

8.21 FLEX ANCHORS

The primary flex anchor load is typically intended to be wind; but for skins with architectural facings, if volume-change properties of the layers are unequal, there will also be forces on the anchor and the bonding pad to restrict bowing. With all skins, the flex anchors should provide minimum restraint against in-plane volume change.

In one method of attaching the panel skin to the stud frame, the weight of the skin is transferred to the frame through bending of the flex anchors, as in **Figure 8.13**. To ensure structural integrity, the anchors must be of ample rigidity and strength to carry their tributary weight, as well as wind loads; while still remaining flexible enough to allow in-plane volume change movements of the skin without excess restraint. This method is recommended only for panels small enough that flex anchor restraint stresses, when combined with other stresses, are within acceptable limits.

Figure 5.2 shows the most common type of flex anchor. Although it has many variations (**Figure 8.15**), it is usually made with a smooth, round rod about 6–10 mm in diameter. Diameter is determined by the wind load, spacing, the distance from the skin to the frame, and by whether or not a separate gravity anchor is provided. It is welded at the top of the leg for flexibility. A square bar may be used for fillet welding convenience. A flat bar or sheet metal strip is sometimes used for more strength parallel to the steel stud. In this instance, the anchor may be attached to the frame with screws so less restraint is provided. A welded strip type may also be used as a gravity anchor.

Regardless of which anchor, or combination of anchors, is used, the principle of strength with minimum in-plane restraint must remain the primary consideration. This is important in both design and construction. Designers often inadvertently create excess restraint while trying to ensure strength.

If the flex anchor is in the yield range, the designer may need to consider low-cycle fatigue in the design of the anchor for wind load and other cyclic movements.

Unsupported edges of GRC panels can bow or warp. This can present a problem with panel alignment, as well as an unsightly joint. It is recommended that the distances from the edges of the skin to the anchors be kept equal and small to minimise warping as in **Figure 8.16(d)**.

8.22 GRAVITY AND SEISMIC ANCHORS

In larger, heavier panels, if the skin is attached to the stud frame with flex anchors only, they may become so stiff that restraint creates overstress of the skin. If the dead load is carried separately by gravity anchors, the flex anchors can be small (6-mm diameter) to substantially reduce the in-plane restraint.

In its plane, the skin is quite rigid. If the stud frame is made sufficiently rigid with diagonals, or stiff upper and/or lower tracks, as in **Figure 8.16(c)**, the load of the skin can be carried with a series of gravity anchors. This is usually accomplished with the trussed-rod gravity anchors shown in **Figure 8.16** and **8.12**.

If the frame is supported at two connector studs (or tubes), it is often advantageous to support the skin's dead weight from the same two members. This allows the in-plane rigidity of the stud frame to be lower, since the skin's weight is carried by the connector studs directly to the structure connections. The connector studs (or tubes) may need strengthening locally or full height. This two-point gravity transfer is usually accomplished with the plate gravity anchor shown in **Figures 8.16(b)** and **8.12**. By adjusting the plate height and thickness, vertical strength of the anchor is achieved without sacrificing horizontal flexibility. Additional flexibility can be achieved by slotting the leg plate as in **Figure 8.14(a)**. Additional load capacity can be achieved by putting holes or notches in the cross plate to increase its bearing area in the bonding pad.

Gravity anchors should be placed on one horizontal line, since they do not allow vertical movement as caused by temperature and moisture variations. Gravity anchors should be positioned so that skin bending stresses of three-dimensional panels (ie with returns or recesses) are minimised. It is preferable to locate gravity anchors near the bottom of the skin so that its own weight puts it in compression; however, other conditions may dictate otherwise.

Since the gravity anchors set the location of the vertical 'neutral' point from which movement radiates, it is sometimes advantageous to put the gravity anchors at mid-height. Whilst it is preferable to have permanent stresses compressive, the tensile stresses produced by the bottom half of the panel hanging from the gravity anchors are usually low.

Where the panel shape creates a natural seat, it can be fitted to a shelf on the stud frame to carry the weight of

the skin, instead of a gravity anchor. This can also be accomplished with the addition of GRC corbels. These must be used in a manner that does not restrict movement.

In seismic areas, the in-plane seismic load resistance needs must be achieved without excess restraint of volume change. If seismic load is taken by typical studs, their weak axis stiffness may need to be investigated. With a flat plate gravity anchor system, it may be possible to strengthen one, not both, of the gravity anchors to carry

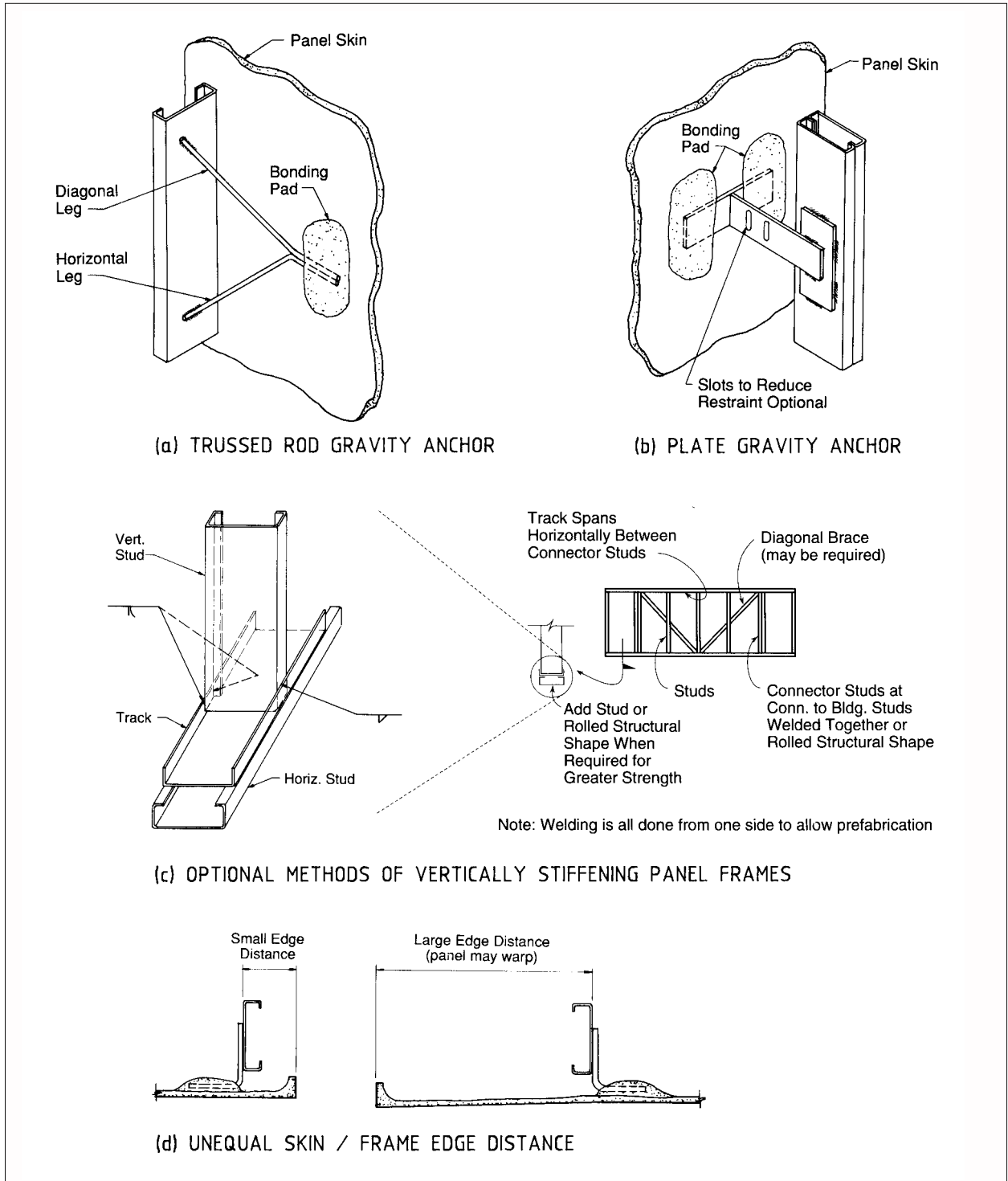


Figure 8.16 Anchors and stiffening details

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8.24

the seismic load. A horizontally oriented flat plate anchor may also be used to carry the longitudinal seismic load to the stud frame, as shown in **Figure 8.17**. The seismic anchor will usually set the location of the horizontal 'neutral' point, so it should preferably be at the mid-length of the panel. There will be rotational forces which the anchor system must carry if the seismic anchors are not on the same horizontal line as the centre of mass of the skin.

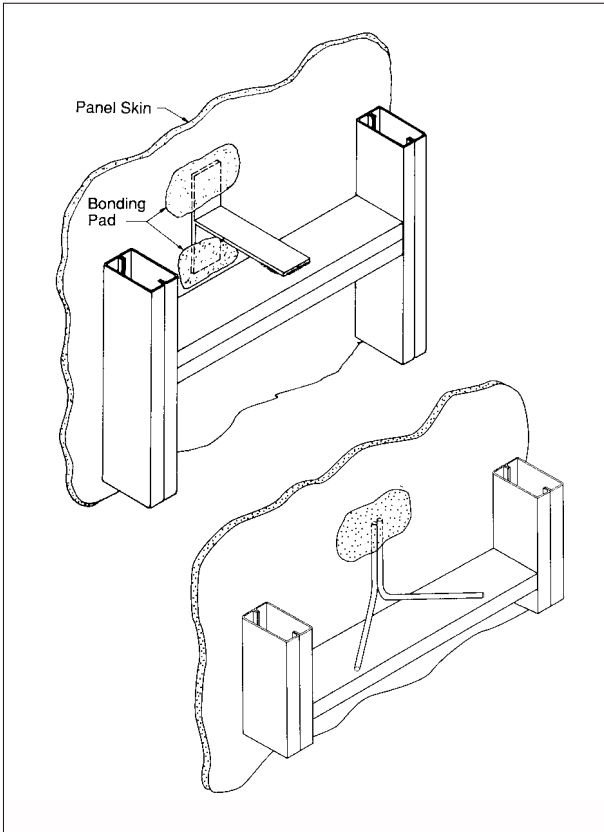


Figure 8.17 Plate and truss seismic anchors

8.23 ANCHOR EVALUATION

In addition to material variables, the strength and performance of the skin anchors is highly dependent on the technique of the individual applying the bonding pad. The properties achieved in practice will be dependent on type of anchor used, quality of materials, degree of compaction, thickness and area of bonding pad, and adequacy of curing.

It is necessary that each manufacturer perform a sufficient number of tests, to develop a data base from which a limiting anchor load can be determined, for each type and size of anchor and set of conditions. If unaged tests are used for production quality control, as is usual, both aged and unaged anchor specimens must be tested prior to design; all specimens must be made in an identical manner to the production anchors.

For pre-design/production testing, a minimum of twenty aged and twenty unaged specimens should be made for each type of anchor and procedure. The aged to unaged ratio for the particular circumstances should be used together with the production test values to determine the limiting load allowed per anchor.

Comparison of aged and unaged results will allow the method of manufacture to be assessed in relation to fatigue and ageing. Clearly, the aim is to generate a detail where the variance between the two is small. Once the variance is agreed by the engineer, tests at 7 or 28 days can be utilised for day-to-day quality assurance.

Material factor for bonding pads = 2.5.

Tests have indicated the following unaged ultimate strength ranges for various types of anchors.

Type of Anchor and Load		Ultimate Load (unaged)
Tension	Flex anchor (Figure 8.15)	2–5 kN
Shear	Trussed rod gravity anchor (Figure 8.16)	4–8 kN
Shear	Flat plate gravity anchor (Figure 8.16)	8–16 kN

8.24 IN-PLANE ANCHOR RESTRAINT STRESSES

The purpose of the flexible anchorage of the panel skin to the stud frame is to transfer perpendicular (eg wind) loads from the skin to the frame, while still allowing independent in-plane movements between the two.

There are substantial panel skin movements caused by temperature and moisture changes. If the flex anchor legs are too rigid, the restraint can induce high in-plane stresses in the skin.

Considerations in the determination of the panel skin thickness attachment include:

- Thickness and mix design for both the backing and facing
- Size and shape of the panel
- Location of openings and irregularities
- Movement due to temperature and moisture variation.

Flex anchor spacing and orientation, and the panel dimension from the 'neutral' point all have a significant effect on the dimensional change of the skin. Column strength and lateral buckling of the flex anchor are seldom a problem.

The largest and easiest parameters to control are the diameter, length and yield strength of the anchors. If the anchor toes are perpendicular to the stud, and point away from it and toward the middle of the panel, the initial drying shrinkage tends to pull the anchor away

from the stud rather than making it bear against it, where pressure could reduce the effective length of the leg. Some manufacturers prefer to put a small bend in the anchor so that its only contact with the stud frame is at the weld.

In many instances, the flex anchors are stressed to their yield level. Flex anchor cyclic stresses in excess of yield stress may cause material fatigue. For simplicity in skin stress analysis, all anchors can be assumed to exert a restraining tensile stress in the panel skin equivalent to that which develops when their yield strength is reached. This simplified approach is suggested in recognition of the difficulty in quantifying all factors and is conservative for skin stresses.

For skins with architectural facing, all stresses due to in-plane volume change, or from any other source, should be assumed to be resisted entirely by the GRC backing alone.

It should be noted that, for many sizes of panel there is sufficient over-capacity in the anchors to make it unnecessary to differentiate between flex anchor and gravity anchor. Nevertheless, the designer must still be satisfied that the load path and movement is properly accommodated in design.

8.25 OUT-OF-PLANE RESTRAINT STRESSES

Every effort should be made to make the layers of a two-material skin have similar thermal and moisture volume change properties.

Even though the skin is quite flexible, it does tend to bow with differential inter-laminar volume changes, which create out-of-plane forces, in addition to the in-plane forces already discussed.

Skin bow, if unsupported, could be computed from its properties, dimensions, and differential volume change. The force to remove the bow would then be exerted on the skin, anchors and frame which could be appropriately analysed.

8.26 STUD FRAME DESIGN

Stud frames are usually made up of cold-formed steel studs and/or structural tubes, but may contain any structural shape. They are prefabricated, usually including the skin anchors, and set into place over the freshly sprayed skin, with jigs for precise location with respect to the skin. The frame should be designed for stripping, handling and in-service loads. Welding should conform to relevant Australian Standards (specifically AS 1554.1).

Prefabrication, panelisation, and handling induce loads that studs do not traditionally encounter. The skin should not be relied on to provide bracing for stud stability.

Depending on stud gauge, dimensions, support conditions, interior finish, etc, bridging may be required to prevent buckling.

Due to the non-restraint requirement of the skin anchors, the skin cannot be assumed to add to the stud strength as in some composite masonry/stud applications. Since there is an interconnection between the skin and the stud frame, when the skin shrinks and the frame doesn't, the panel may tend to bow. The frame must have sufficient rigidity perpendicular to its plane to resist this bowing, as well as any bowing due to differences in volume-change properties of two-material skins. The frame is recommended to be fixed to the supporting structure with four fixings; two to carry vertical load (one sliding, one fixed) and two for lateral restraint only.

The load from the panel skin is transmitted through the gravity and flex anchors to the studs. From the studs, the load is transmitted via horizontal tracks and vertical connector studs to the structural connections and then to the structure, see **Figures 8.13** and **8.12**. If the skin's gravity anchors are at each or alternate studs, diagonal braces or stiffening of the horizontal track may be required as illustrated in **Figure 8.16(c)** and **8.12** to provide sufficient in-plane frame rigidity so that each stud supports its tributary portion of vertical loads.

Greater member capacity is required at the structure connection locations since they will carry the loads collected by the horizontal tracks. Increased capacity of these connector studs is usually accomplished by using double or boxed studs, tubes, or rolled structural shapes. See **Figure 8.18**.

It is common to reinforce light-gauge connector studs by welding heavier plate or angle assemblies to them in order to achieve better distribution of the loads, as in **Figure 8.18**. Rolled structural shapes can be used instead of steel studs as in **Figure 8.18**. Field welding to steel with thicknesses lighter than 12 gauge is not advisable.

Often, panel to panel alignment connections as in **Figure 11.2** are beneficial. They can usually be added as a field modification without changing the action of the panel connection system.

Deflection perpendicular to the plane of the panel should be limited to prevent damage to interior finishes or windows that are attached to the stud frame. $L/240$ is suggested. Interior finishes and windows should be compatible with the chosen value.

The stud frame should have sufficient in-plane rigidity so that the force in the panel tie-backs due to storey drift is not transferred to the skin anchors.

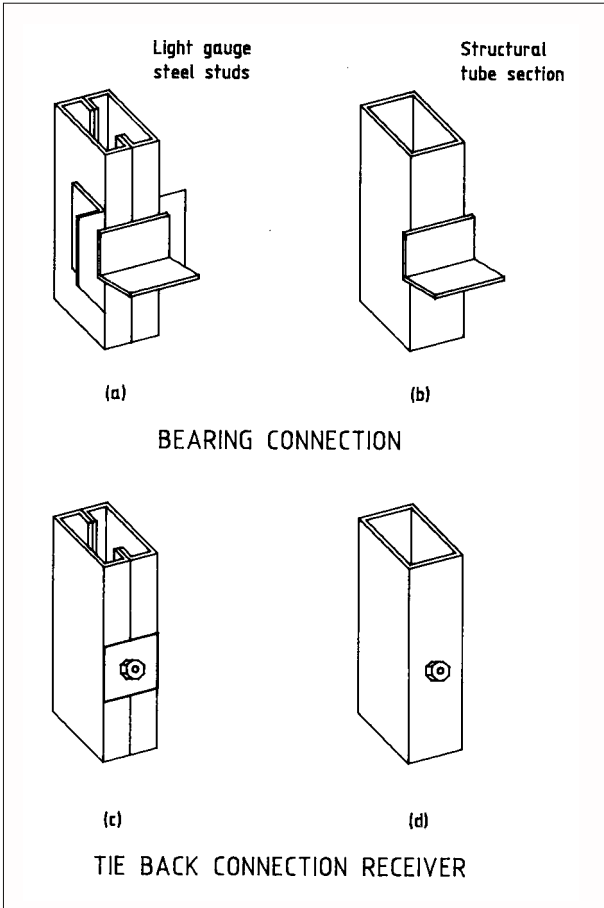


Figure 8.18 Bearing and tie back connections

8.27 INSERTS AND EMBEDMENTS

There are often requirements for attachments of other items to GRC panels. They may be required, for example, on a frame panel skin for a sign, or sprayed in at the inside of the integral rib panel for its connection to the structure as in **Figure 8.20(f)**. The same principles apply; all should be tested for capacity and be utilised in such a way as to minimise unwanted restraint.

Fastening details should be designed to transfer the force to as large an area of the GRC as possible. Encapsulated inserts should be set with jigs to protrude slightly above the surface of the GRC so they do not become inadvertently recessed. Attachments to inserts should bear directly upon the insert, not the GRC surface, to prevent pullout of the insert if the bolt is over-tightened. Very high loads can be exerted when bolts are over-tightened, leading to bolt failure or local failure of the GRC. The use of oversized washers is recommended when direct bolting is used. Elastomeric washers may be used, particularly when the GRC bearing area is not smooth.

Many fasteners used with precast concrete panels are also suitable for GRC panels. Corrosion-resistant inserts and embedments are recommended. They must be properly embedded in built-up homogenous GRC bosses

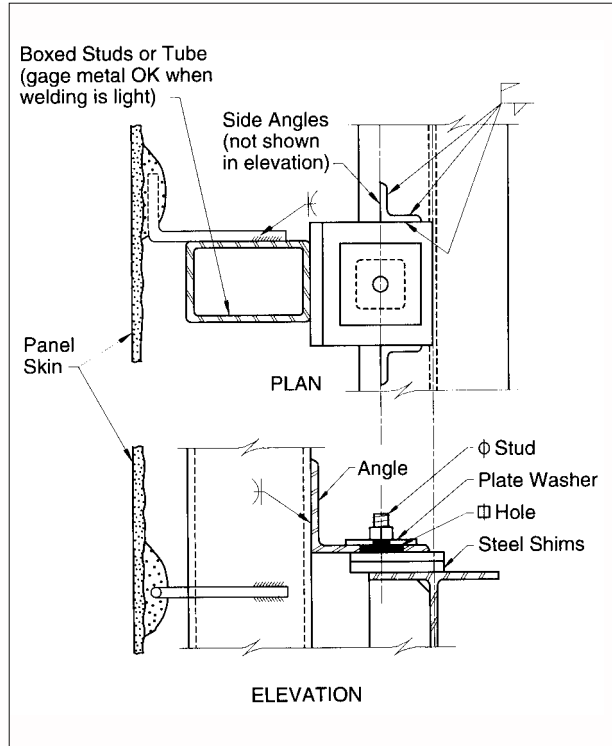


Figure 8.19 Bearing connections

or bonding pads to develop their strength and distribute the load. As care is needed to encapsulate inserts, the area should be easily accessible during manufacture. Good quality material must be used around the embedments. Waste material, such as over-spray, is not acceptable.

Flexural tension in the area of embedments may reduce their pull-out capacity. Rigid embedment items that are bonded to the GRC, such as steel more than 150 to 300 mm long, may create undesirable restraint to volume change and cause over stressing of the GRC. With adequate precautions, over stressing can be avoided. These precautions include: isolation of embedded items, use of bond-breaker, discontinuity of a rigid item, or an increased section of GRC.

Exterior items, such as signage, should have sliding hardware to be set to stand off, on long bolts that can flex. Heavy items should connect to the stud frame or the main structure, not the panel skin. The fastening system must not prevent the movement between the panels and the main structure anticipated by the connection system.

It is preferable in connection design for integral rib panels to have the main support at the bottom of the panel so that the panel is put into compression under its own weight.

If panels are excessively restrained, such as by over tightening of nuts and bolts, large or sharp changes in section thickness, or by attachment of adjacent components (eg window frames), movement of the panel

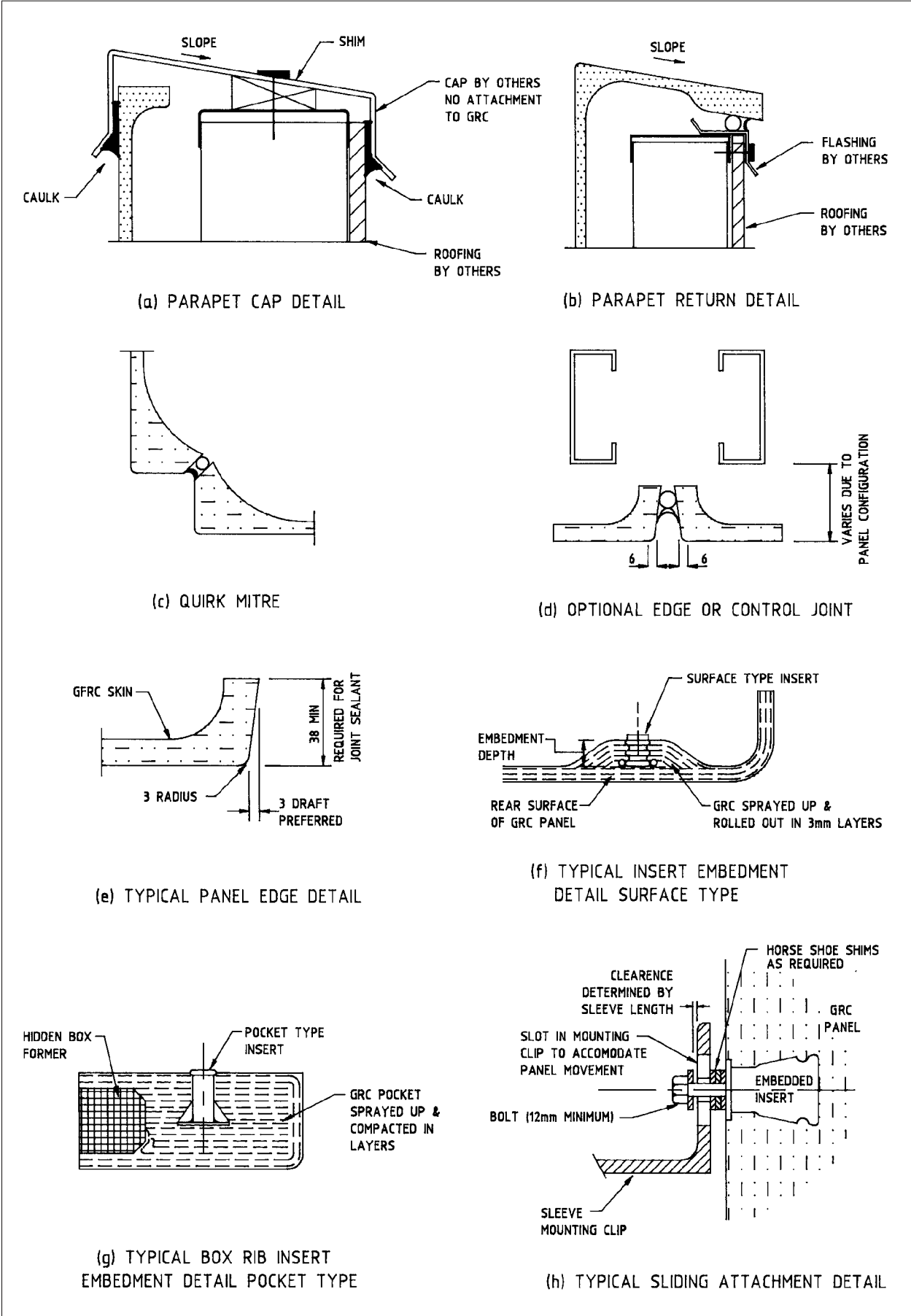


Figure 8.20 Typical architectural details which may be modified to satisfy specific project requirements

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skin due to temperature or moisture changes is also restrained. As the panel ages, any unrelieved strains could exceed the strain capacity of the GRC, resulting in cracking.

The fastening detail must provide sufficient three-dimensional adjustment for construction tolerance and sufficient movement ability to accommodate volume changes and allow for structure movements. Slotted and/or oversize holes in connections, or special fasteners, are the usual means to accommodate these requirements. Usually, integral rib panels are fixed at one point, while the other connections have the freedom to move.

Consideration should also be given to environmental conditions, such as a corrosive atmosphere, as well as to fire protection requirements. Corrosion protection of connection elements should be provided to prevent loss of movement. One technique to avoid a corrosion-fused connection is the use of plastic or fibre washers. Dissimilar metals that could lead to galvanic corrosion should not be used.

8.28 CONDENSATION CONTROL

The U-value of a wall must be such that the interior surface temperature will not fall below the dew-point temperature of the room in order to prevent condensation on the interior surface of the wall. In many designs, the desire to conserve energy will dictate the use of lower U-values than those required to avoid condensation.

Water vapour in air behaves as a gas, and will diffuse through building materials at rates dependent on the vapour permeability of the materials and vapour pressure differentials. GRC is a relatively good vapour retarder. Permeance is a function of the water/cement ratio and polymer content of the GRC. A low water/cement ratio, such as that used in GRC panels results in low permeance.

The lower the outside temperature, the greater the pressure of the water vapour in the warm inside air to reach the cooler, dry, outside air. Leakage of moisture-laden air into an assembly through small cracks when outdoor air pressures are lower than interior pressures, may be a greater problem than vapour diffusion.

Where climatic conditions require insulation, a vapour barrier may be necessary to prevent condensation, and consideration should be given to venting of the wall. Water vapour entering a cool stud frame panel cavity may condense, and over an extended period of time, may reduce the effectiveness of fibre insulation. Water droplets thus formed may also corrode unprotected steel. If the vapour condenses at or near the exterior surfaces, salts in the facing may be carried to the surface and deposited, as efflorescence.

Insulation, if used, should be kept away from the skin to allow air circulation. This will reduce shadowing of the stud frame to the outer surface finish.

The analysis of an assembly for the potential problem of water vapour condensation should consider:

- the differentials between inside and outside temperatures, water vapour pressures and relative humidities;
- temperature gradients through the assembly, the dew point location under design temperatures, and relative humidities;
- resistance to vapour transmission of the components of the assembly; and
- venting to allow water vapour to escape.

8.29 ARCHITECTURAL DETAILS

Figure 8.20 show some typical architectural details. These should be modified to satisfy specific project requirements.

Referenced Documents

The following documents were referred to in Chapter 8, in order of appearance:

- AS 1170.1:2002 *Structural design actions - Permanent, imposed and other actions.*
- Fordyce and Wodehouse (para 8.13) *GRC and Building - A design guide for the Architect and Engineer for the use of Glass Fibre Reinforced Cement in Construction* 1983 Butterworth London.
- AS 3600:2001 *Concrete Structures.*
- AS/NZS 1554.1:2004 *Structural steel welding - Welding of steel structures.*

9 ESTABLISHMENT and QUALITY CONTROL of GRC CHARACTERISTIC STRENGTH

9.1
9.2
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9.1 GENERAL

The manufacturer should maintain written records of all test results together with details of elements produced. The information should include the dates on which the tests were carried out and on which the elements were formed, demoulded, cured and stored. All records should be made available to the Engineer for inspection.

9.1.1 Test Boards

Test boards should be produced at a frequency agreed by the manufacturer and the Engineer. The actual frequency of test board production will depend on the production rate of the finished elements and the quality required. For work of a high quality, it would be prudent to use daily testing.

The test boards should be large enough for test coupons described in Clause 9.2 to be cut without using the areas at the edges of the test board which may be of non-uniform thickness and glass orientation.

After sampling of the material, immediately after spraying or mixing for glass content and wet bulk density, test boards should be stored with the appropriate finished elements during the curing period and should be marked for identification with the finished products. When the finished elements are removed from the curing area, the test boards should be transferred to the testing laboratory for testing.

9.2 TESTS

The following tests should be carried out on coupons cut from the test boards in accordance with BS EN 1170:1998 *Test Methods for Glass-Fibre Reinforced Cement* (no Australian equivalent).

- Glass Content
- Wet Bulk Density
- Dry Bulk Density
- Modulus of Rupture
- Limit of Proportionality.

The following additional tests described in BS EN 1170:1998 may be prescribed by the Engineer:

- Water/Solids Ratio
- Water Absorption
- Apparent Porosity.

9.3 TEST REQUIREMENTS

9.3.1 Glass Content

For sprayed-up material the glass content should be as nominated by the mix design but not more than 6.3% by weight of total composite. For premix material the glass content should be as nominated by the mix design but not more than 3.5% by weight of total composite.

The glass content should not vary from the specified amount by more than 20%.

9.3.2 Modulus of Rupture (MOR)

The Characteristics MOR (MOR_k) is defined as the value which 95% of all the mean strengths of the individual test boards (see Clause 9.2) should exceed. The overall target mean MOR (MOR_t) should be taken as:

$$MOR_t = MOR_k + (1.64 \times SD)$$

where SD is the standard deviation of the accumulated test board mean MOR values.

Use the actual standard deviation if more than 40 test boards have been tested. Otherwise, assume a standard deviation of 2 MPa.

9.3.3 Limit of Proportionality (LOP)

The characteristic LOP (LOP_k) is defined as the value which 95% of all the mean strengths of the individual test boards should exceed. The overall target mean LOP (LOP_t) should be taken as:

$$LOP_t = LOP_k + (1.64 \times SD)$$

where SD is the standard deviation of the accumulated test board mean LOP values.

If less than 40 test boards have been produced, assume a standard deviation of 1 MPa.

9.3.4 Wet Bulk Density

Wet bulk density should exceed 2.0 t/m³

9.3.5 Dry Bulk Density

Dry bulk density should exceed 1.8 t/m³

9.4 COMPLIANCE

9.4.1 Conditions

Results of the individual test boards' mean MOR and LOP values will be treated statistically for compliance with the following conditions:

- No single test board mean should be less than 85% of the characteristic value.
- The average of overlapping groups of four successive results must be greater than the characteristic value (M_k, L_k) plus half the margin.

9.5
9.6

The margin is defined as the difference between the characteristic value and the target mean prior to the last four results ($M_t - M_k, L_t - L_k$).

9.4.2 Non-compliance

Where any result or set of results fails to comply with Clause 9.4.1, the elements represented by those results should be deemed to be defective and must be individually assessed by the certifying engineer.

9.5 ACCEPTANCE OR REJECTION OF GRC

The manufacturer should establish a characteristic strength for a particular GRC mix. The definition of a characteristic strength is a value of modulus of rupture at 28 days derived from 40 test boards over 80 different days of GRC manufacture. The coupons used to assess that manufacture should be stored and cured in identical conditions to the manufactured product. Identical means of production, in particular compaction, should be utilised in generating the coupons.

The factory should operate with a Quality Control Manual (for guidance see Reference 2). The manual should be signed by the product manager, the managing director of the company and the Engineer responsible for approving incorporation of the product in the particular job.

The coupons are therefore representative of not only the mix used in production but also the Quality Control Procedures of the factory. Where items of manufacture are involved which are fundamental to the adequacy of design, then additional tests are required. Pull-off or shear tests for flex and gravity anchors should be carried out in accordance with procedures nominated by the Engineer.

Where integral GRC ribs are utilised in design, sample panels incorporating the ribs should be made utilising identical compaction methods over void formers. Load testing in accordance with the standard bending test should proceed. Acceptance or rejection will be confirmed by the Engineer following the principle of the pull-off test for anchors.

Where sandwich panels are proposed, coupons should be cut from sample panels made in the same manner as the main panels in order that the coupons reflect the compaction achieved on the mould face and the top surface. Testing may be by means of the whole sample panels or by cutting the skins from the core and testing as conventional coupons, always ensuring that the external face is in tension.

Coupons for vibration cast elements should be generated from geometric shapes representative of the product. In the case of standard products, a small version of the product should be made each day and then cut up for testing.

The version should be large enough to satisfy standard coupon testing requirements. Where a special product is generated of limited production duration, the coupon sample should be of a geometric shape approved by the Engineer as being appropriate.

Anisotropic properties is an area of great concern. Coupons should be cut from larger test boards in order that the strength characteristics of GRC are assessed as follows:

- 2D product: X direction
Y direction
45°
- 3D product: X direction
Y direction
Z direction

This is particularly important for vibration cast production since the strength may vary by as much as 50%.

For whatever product, mix, and method of manufacture, once the 80 coupons are obtained, statistical analysis should be used to obtain the characteristic value.

Once the characteristic value is obtained, individual day-to-day compliance for product should be carried out utilising Clause 9.4.1. As product is rejected, so its results are eliminated from the general bank of test data. Statistical analysis of the remaining results should be carried out for each 40 days production or each 40 days of actual testing (see Clause 9.6).

Isolated low values does not mean all the GRC is defective. Once a basic mix is approved (ie 80 days of manufacture) those low values should relate only to those panels directly affected.

9.6 FREQUENCY OF TESTING

The frequency of testing is to be agreed by the Engineer and the manufacturer and identified in the specification.

Each and every product must have a characteristic strength which can be assigned to it. Logically, that should be achieved as soon as possible. Thereafter, the frequency of testing is for the manufacturer to decide on the basis of how much product he wishes to place at risk. If the frequency of testing is low, and failure to comply occurs, then all product in that period must be subject to random sampling of actual product from each day's testing. The random sample is either load tested to failure or some form of non-destructive testing is identified which allows the Engineer certifying the product to approve it.

It is suggested that the frequency of testing should identify to that discussed in Reference 2, except where specified product quality is low or there is no structural application. However, it is difficult to justify not using full-scale, regular testing.

9.7 TREATMENT OF COUPONS

It is important that coupons reflect the mix design, method of manufacture and the method of curing.

For all 7-day testing, coupons should be tested as they are being cured. For all 28-day testing, the treatment of the coupon should reflect the final application of the product. If the GRC is to be cured, and stored until the moisture content is less than 12% and then coated on each side, then the coupons should be tested to reflect the as-built condition. If GRC is to be utilised such that it can absorb uncontrolled volumes of water from the atmosphere, ie it is unprotected on one or two faces, then the coupons should be tested 'soaked'.

9.8 FINISHES

Unless utilised in design by the engineer, all coupon testing should not include the applied coatings.

9.9 LONG-TERM STRENGTH OF GRC

Worldwide, reference is made to 7- and 28-day testing for cementitious materials. This is logical since it suits QC procedures and accommodates the predominant periods of matrix strength gain.

Historically, it has always been considered that the alkali resistant fibre is attacked. More-recent work, however, suggests it is the development of crystals around the fibres. Actual creep of the bond between the mortar and the fibre due to stress has a role.

Since AR fibres became commercially available in the early 1970s, bringing into being a new worldwide industry based on GRC, research both within the industry and the academic world has strived to improve the long-term properties of the composite.

AR fibre has been progressively refined so as to improve the long-term performance and this has, in turn, had a significant impact on both GRC component development and application, and specifier confidence.

At the same time, research on matrix properties and performance has been aimed at stabilising the chemical reactions that occur within a hydrating cementitious composite and the effects these reactions have on the reinforcing fibre. This research has resulted in the development of a range of rapid-set and sometimes low-alkali cements whose chemistry is, however, different from portland cement, making long-term prediction of properties based on existing accelerated ageing tests more difficult and open to question.

Whilst the new cement matrices have a valuable contribution to make for components in non-critical applications where rapid demould, in particular, is important, the use of these new cements for products such as building cladding panels needs to be examined carefully. They are also very expensive.

Recent research has resulted in the production of a highly workable mix with excellent fibre incorporation which significantly increases ultimate factors of safety and design flexibility for GRC components.

Standard GRC is known to lose some of its initial strength and become less ductile over a long period of time. Although the design process accounts for this change in properties, and there is little evidence to show that this is a problem, it is still perceived by some as being a disadvantage and is frequently used as an argument against GRC products in competitive situations.

There is now strong evidence to show that when AR fibres are used this loss of strain capacity is not due to alkali attack on the fibre by cement. It has been established that it is due to the development of lime crystals and calcium silicate hydrate (CSH) around and within the bundles of glass filaments. The lime, calcium hydroxide, $\text{Ca}(\text{OH})_2$, is a by-product of the cement setting (the hydration processes) and it is initially present as an aqueous solution. This solution is drawn by capillary action into the fibre bundle and later crystallises, filling the pores and locking the fibre into the cement matrix, thus preventing the slippage that exists in young GRC. It is this energy absorbing slipping of the fibres that gives GRC its remarkable toughness characteristics.

9.10 ACCELERATED AGE TESTING

Not widely discussed is the impact on strength of the environment in which the GRC is to be located.

Figure 8.3 shows GRC loss of strength with time.

Original research work by Pilkington Bros and latterly Cem-Fil International has established that different climates result in differing degrees of weathering. Empirically, they have chosen the 50°C temperature as giving the best fit towards actual age testing of product. Further, hot climates cause much more rapid ageing than cold climates. For example, for the UK, one day stored in water at 50°C is equivalent to 100.1 days of natural weathering. For two Australian sites (Cloncurry and Innisfail) one day is equivalent to 13.4 and 19.1 days respectively of natural weathering.

Based on this, to plot the loss of strength for a GRC product over 25 years for Australia, proceed as follows:

- Create a container and maintain water at 50°C.
- Using a conversion of 16 days/day
 - 25 years = 570 days of testing (19 months)
 - 5 years = 114 days (4 months).
- Install 60 coupons in the bath and test one every 10 days. This gives a result for every 160 days.
- Plot results to achieve the long-term predicted strength.

9.10

Results for Australia show that the loss of strength tends to occur over the first 5 years. Thus, a good indication of likely long-term strength can be obtained after 4 months' testing.

All coupons should be appropriately cured in accordance with Chapter 6, prior to testing. All testing is in accordance with standard procedures.

If the in-service requirement is for the GRC product to be coated, then coupons tested should be similarly treated prior to testing.

Referenced Documents

The following documents were referred to in Chapter 9, in order of appearance:

- BS EN 1170:1998 *Test Methods for Glass-Fibre Reinforced Cement*
- *Manual for Quality Control for Plant Production of Glass Fibre Reinforced Concrete Products* MNL-130-91 PCI, 175 West Jason Boulevard, Chicago, IL. 60604 USA.
- *Recommended Practice for Glass Fibre Reinforced Concrete Panels - Third Edition*. PCI, 175 West Jason Boulevard, Chicago, IL. 60604 USA.

10 CONTRACT CONSIDERATIONS

10.1 RESPONSIBILITIES

With GRC panels, as with many construction materials, there is a potential for overlapping project responsibilities and subsequent difficulties. Problems may develop when responsibility for structural design and handling stresses, manufacturing techniques, installation, connection hardware, caulking and cleaning are not determined in advance. To ensure proper coordination, the full building team should be involved in defining the responsibilities.

10.2 CONTRACTUAL RESPONSIBILITIES

Areas of contractual responsibility that should be clearly assigned in the contract documents are:

- Panel design
- Connection hardware
 - attached to the building frame
 - furnished or provided loose
 - secured to the panel
 - integral with the panel
- Panel installation
- Sealing or coating
- Joint caulking
- Panel cleaning.

The GRC manufacturer is responsible for delivering a clean panel. The general contractor must assume the responsibility of protecting panels from subsequent damage and soiling after accepting panels from the carrier, or after the erection of the panels, unless otherwise nominated.

Specialty items anchored in or attached to the panels should be supplied to the manufacturer by the appropriate trade along with detailed instructions.

The National Precast Concrete Association Australia in its publication, *Precast Concrete Handbook* provides in Chapter 12, *Contract Issues*, a quite comprehensive discussion on general and design responsibilities.

10.3 DESIGN RESPONSIBILITY

Design calculations should be performed under the supervision of the design Engineer. The GRC manufacturer should be prepared to assist with the designs of panels and connections. The Client's designer (architect/engineer) maintains overall design responsibility. **Table 10.1** offers options as to how the lines of responsibility can be established within a given project.

The designer can benefit from early contact with experienced manufacturers who can offer constructive advice during preliminary design.

It is common practice for the designer to rely on the GRC manufacturer for handling and erection procedures, and for ensuring that the unit is adequately designed for loads incurred during manufacturing, handling, shipping and installation. All procedures should be checked to ensure that they do not cause:

- detrimental cracking;
- structural damage;
- architectural impairment; or
- permanent distortion.

Contract drawings prepared by the designer should show connections in sufficient detail to permit design, estimating and tendering. Panel manufacturers, during the preparation of shop drawings, usually review connections for tolerances, clearances, practicality and performance. The manufacturer should call to the designer's attention any unforeseen problems.

The Head Contractor is responsible for the co-ordination and location of all panel-bearing surfaces and connections on the structural frame. Changes, other than adjustments within the prescribed tolerances, require approval by the designer.

10.4 TOLERANCE – CLADDING

10.4.1 Tolerance

Tolerance is the specified permissible variation from requirements of the contract documents. Tolerances should be provided for dimensions, locations and other relationships. Erection and manufacturing tolerances apply to GRC as they do to other building materials.

Tolerances should be established for the following reasons:

- **Structural** – To ensure that structural design properly accounts for factors sensitive to variations in dimensional control. Examples include eccentric loading conditions, bearing areas, hardware and hardware anchorage locations.
- **Feasibility** – To ensure acceptable performance of joints and interfacing materials in the finished structure.
- **Visual** – To ensure that the variations will be controllable and result in an acceptable looking structure.
- **Economic** – To ensure ease and speed of production and erection by having a known degree of accuracy in the dimensions of products.
- **Legal** – To avoid encroaching on property lines and to establish a standard against which the work can be compared in the event of a dispute.
- **Contractual** – To establish a known acceptability range, and also to establish responsibility for developing, achieving and maintaining mutually agreed tolerances.

10.4

Table 10.1 Design responsibilities

Responsibility of Designer (Architect/Engineer)	Responsibility of the Manufacturer of GRC units
<p>Option I</p> <p>Provide complete drawings and specifications detailing all aesthetic, functional and structural requirements, plus dimensions.</p>	<p>The manufacturer should make shop drawings (erection and production drawings), as required, with details as shown by the designer. Modifications may be suggested that, in the manufacturer's estimation, would improve the economics, structural soundness or performance of the GRC installation. The manufacturer should obtain specific approval for such modifications. Full responsibility for the GRC panel design, including such modifications, should remain the designer's. Alternative proposals remain within the parameters established for the project. It is particularly advisable to give favourable consideration to such, proposals, if the modifications are suggested so as to conform to the manufacturer's normal proven procedures.</p>
<p>Option II</p> <p>Detail all aesthetic and functional requirements but specify only the required structural performance of the GRC units. Specified performance should include all limiting combinations of loads together with their points of application. This information should be supplied in such a way that all details of the unit can be designed without reference to the behaviour of other parts of the structure. The division of responsibility for the design should be clearly stated in the contract.</p>	<p>The manufacturer has two alternatives:</p> <p>(a) submit erection and shop drawings with all necessary details and design information for the approval and ultimate responsibility of the designer.</p> <p>(b) Submit erection and shop drawings for general approval and assume responsibility for part of the structural design, ie the individual units but not their effect on the building. Manufacturers accepting this practice may either stamp (seal) drawings themselves, or commission engineering firms to perform the design and stamp the drawings.</p> <p>The choice between alternatives (a) and (b) should be decided between the designer and the manufacturer prior to tendering with either approach clearly stated in the specifications for proper allocation of design responsibility.</p> <p>Experience has shown that divided design responsibility can create contractual problems. It is essential that the allocation of design responsibility is understood and clearly expressed in the contract documents.</p> <p>The second alternative is normally adopted where the architect does not engage a design engineer to assist in the design.</p>
<p>Option III</p> <p>Cover the required structural performance of the GRC units as in Option II and cover all or parts of the aesthetic and functional requirement by performance specifications. Define all limiting factors such as minimum and maximum thickness, depths, weights and any other limiting dimensions. Give acceptable limits of any other requirements not detailed.</p>	<p>The manufacturer should submit drawings with choices assuming responsibilities as in Option II.</p> <p>The manufacturer completes the design in accordance with the specified performance standards and submits, with the tender, drawings and design information including structural calculations. The manufacturer accepts responsibility for complying with the specified performance standards. After acceptance of the tender, the manufacturer submits shop drawings for review by the designer and for the approval of the head contractor.</p>

The architect should be primarily responsible for co-ordinating the tolerances for all work with the requirements of other trades which adjoin the construction.

It should be understood by those involved in the design and construction process that tolerances shown in **Table 10.2** must be considered as guidelines for an acceptability range and not limits for rejection. If these tolerances are met, the member should be accepted. If these tolerances are exceeded, the member may still be acceptable if it meets any of the following criteria:

- Exceeding the tolerances does not affect the structural integrity or architectural performance of the member.

- The member can be brought within tolerance by structurally and architecturally satisfactory means.
- The total erected assembly can be modified economically to meet all structural and architectural requirements.

The enforcement of tolerances should be based on the technical judgement of the designer. This design professional is able to decide whether a deviation from the allowable tolerances affects safety, appearance, or other trades. In building construction, very little out-of-tolerance work, whether it is masonry, insitu concrete, steel, or precast concrete, has been rejected and removed solely because it was 'out-of-tolerance'.

Table 10.2 Acceptable Product Tolerances

Aspect	Acceptable tolerance
See Figure 10.1	$\leq 3 \text{ m } \pm 3 \text{ mm}$
a = Overall height and width of units measured at the face adjacent to the mould	$> 3 \text{ m } \pm 3 \text{ mm}/3 \text{ m}$ (6 mm maximum)
b = Edge return	+ 3 mm, - 0 mm
c = Thickness:	
c ₁ Architectural facing	$\pm 3 \text{ mm}$
c ₂ GRC backing	+ 6 mm, - 0 mm
c ₃ Panel depth from face of skin to back of panel frame or integral rib	+ 10 mm, - 6 mm
d = Angular variation of plane of side mould	$\pm 1 \text{ mm}/75 \text{ mm}$ depth or $\pm 1.5 \text{ mm}$ total whichever is greater
e = Variation from square or designated skew (difference in length of two diagonal measurements)	3 mm/2 m or 6 mm total whichever is greater
f = Local smoothness	6 mm/3 m
g = Bowing	Should not exceed L/240, unless it can be shown that the member can meet erection tolerances using connection adjustments
h = Length and width of blockouts and openings within one unit	$\pm 6 \text{ mm}$
i = Location of window openings within a panel	$\pm 6 \text{ mm}$
See Figure 10.3	Maximum permissible warpage of one corner out of the other three should be 5 mm/m distance from the nearest adjacent corner, unless it can be shown that the member can meet erection tolerances using connection adjustments.
j = Warpage	
See Figure 10.1	
k = Position of integral items:	
k ₁ Stud frame	$\pm 6 \text{ mm}$
k ₂ Flashing reglets at edge of panel	$\pm 3 \text{ mm}$
k ₃ Inserts	$\pm 12 \text{ mm}$
k ₄ Special handling devices	$\pm 75 \text{ mm}$
k ₅ Location of bearing devices	$\pm 6 \text{ mm}$
k ₆ Blockouts	$\pm 10 \text{ mm}$
See Figure 10.4	
Stud frames should be fabricated within following tolerances:	
a = Vertical and horizontal alignment	6 mm/3 m
b = Spacing of frame members	$\pm 10 \text{ mm}$
c = Squareness of frame (difference in diagonals)	10 mm
d = Overall size of frame	$\pm 10 \text{ mm}$

10.4.2 Product Tolerances

Product tolerance is normally determined by economical and practical production considerations, and functional and appearance requirements. Manufacturing tolerances are applied to physical dimensions of units such as thickness, length, width, squareness and openings.

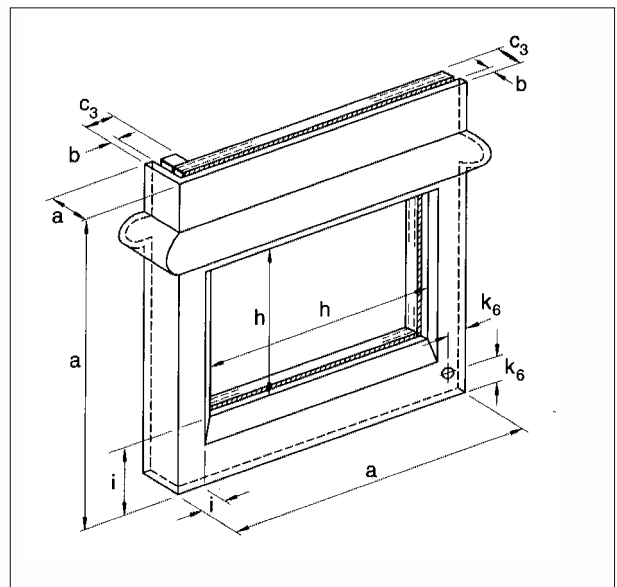
Tolerances should not be set any tighter than necessary for proper function and appearance. So doing will adversely affect cost and production schedule.

The product tolerances for GRC panels have the following significance:

- Length or width dimensions and straightness of the GRC unit will affect the joint dimensions, opening dimensions between panels, and perhaps the overall length of the structure. Tolerances must relate to unit size and increase as unit dimensions increase.
- Tolerances must reflect the inter-relationship of adjacent panels and the number of consecutive panels for which cumulative addition is relevant, otherwise fixing of adjacent panels may be extremely difficult.
- Thickness variation of the GRC panels require the use of furring channels when interior finishes are attached directly to the panel frame.

Warping and bowing tolerances have an important effect on the edge match-up during erection and on the appearance of the erected panels, both individually and when viewed together.

Warping is an overall variation from planeness in which the corners of the panel do not all fall within the same plane. Warping tolerances are stated in terms of the magnitude of the corner variations, as shown in **Figure 10.3**.

**Figure 10.1** Panel tolerance criteria

10.4

Bowing is an overall out-of-planeness condition which differs from warping in that while the corners of the panel may fall in the same plane, the portion of the panel between two parallel edges is out of plane. Bowing conditions are shown in **Figure 10.2**. Differential temperature effects and differential moisture absorption between the inside and outside faces of a panel should be considered in design both to minimise bowing and warping and ensure that the resulting stresses are kept within acceptable limits.

Note that bowing and warping tolerances are of primary interest at the time the panel is erected. Careful attention to pre-erection storage of panels is necessary, since storage conditions can be an important factor in achieving and maintaining panel bowing and warping tolerances.

Differential bowing is a condition for panels which are viewed simultaneously on the completed structure.

The likelihood that a panel will bow or warp depends on the design of the panel and its relative stiffness or ability to resist deflection as a plate member. Panels which are relatively shallow or have a 'flexible' frame, when compared to their overall plan dimensions are more likely to warp or bow.

Panels should be fabricated within tolerances shown in **Table 10.2**.

10.4.3 Erection Tolerances

Manufacturing, interfacing and erection tolerances must be taken into account during the design phase of each project to ensure satisfactory panel installation. Erection tolerances are those required for realistic fit with the building structure. Erection tolerances are determined by the characteristics of the building structure and site conditions and are provided to achieve uniform joint and plane wall conditions. They should be determined on the basis of individual unit design, shape, thickness, composition of materials, and overall scale of the unit in relation to the building. The specified erection tolerances affect the work of several trades and must be consistent with the tolerances as specified for those trades. Where GRC units connect to site work, such as footings or foundation walls, ample erection tolerances are required.

Erection tolerances are of necessity largely determined by the actual alignment and dimensional accuracy of the building frame. The head contractor is responsible for the plumbness, level and alignment of the foundation and structural frame, including the location of all bearing surfaces and anchorage points for the GRC units.

The designer should recognise the critical importance of controlling foundations and building frame alignment tolerances and should include, on the contract drawings, clearance dimensions which make allowances for building frame tolerances such that the structure can be erected safely and economically. If the GRC units are to be installed reasonably 'plumb, level, square, and true', the actual location of all surfaces affecting their alignment,

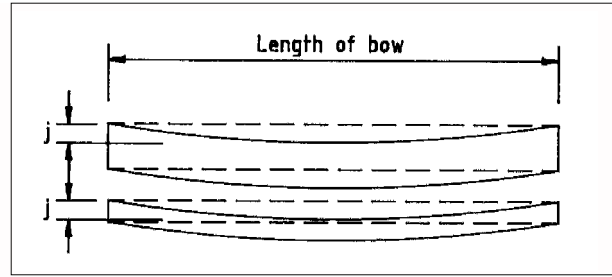


Figure 10.2 Possible bowing conditions

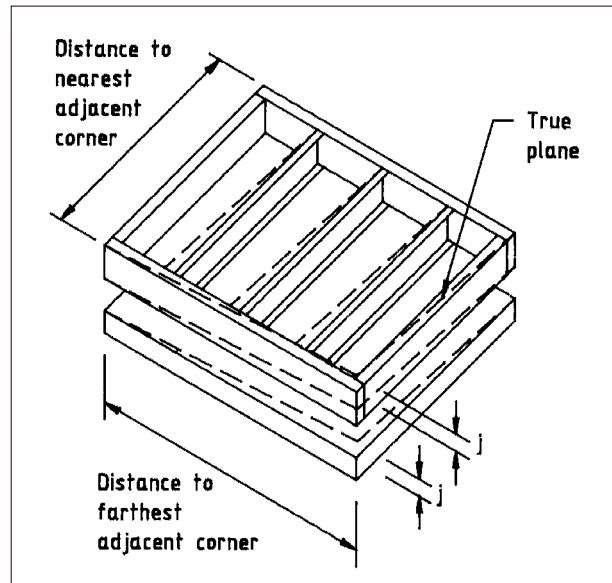


Figure 10.3 Warping definitions for panels

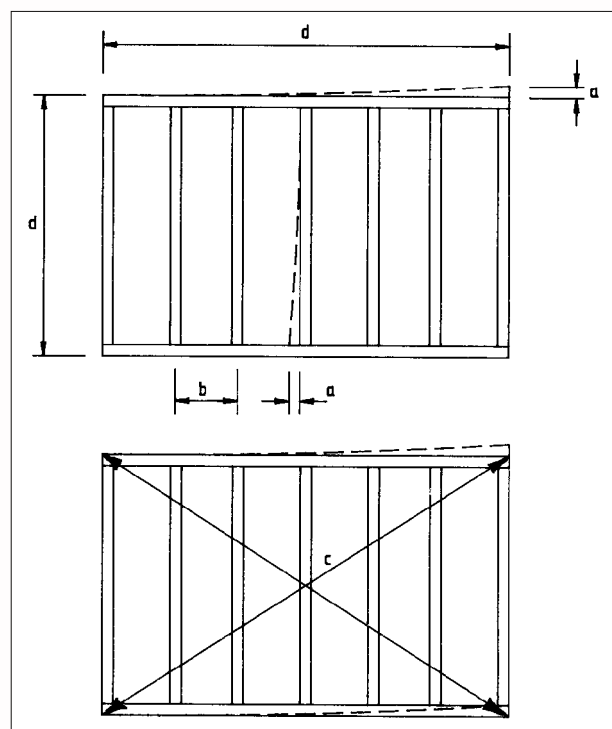


Figure 10.4 Stud frame tolerance criteria

including the levels of floor slabs and beams, the vertical alignment of floor slab edges and the plumbness of columns or walls, must be known before erection begins.

The designer should clearly define in the specification the maximum tolerances to be permitted in the building frame alignment, then should see that the head contractor frequently checks to verify these tolerances are being held. In addition, the designer should ensure that the details in the contract documents allow for the specified tolerances. Lack of attention to these matters often necessitates changes and adjustments in the field, not only delaying the work but usually resulting in unnecessary extra cost, and sometimes impairing the appearance of the units and the completed structure.

Tolerances of the building frame must be adequate to prevent obstructions that may cause difficulty with or hinder panel installation procedure. The structural frame should also provide for the use of standardised connections, ie whenever possible, beam elevations and column locations should be uniform in relation to the GRC units with a constant clear distance between the GRC units and the support elements.

For a cast-in-place concrete frame, the maximum tolerances that should be permitted, unless otherwise stated in the specifications, are those given in appropriate Standards for the frame material be it steel or concrete. Also, greater variations in height of floors are more prevalent in cast-in-place than in other types of structures. This will affect location or mating of the insert in the panel with the cast-in connection device. Tolerances for cast-in-place structures may have to be increased further to account for local trade practices, the complexity of the structure, and climatic conditions. As a result, it is recommended that walls should follow concrete frames in the same manner as for steel frames.

In the determination of tolerances, attention should also be given to possible deflection and/or rotation of structural members supporting GRC panels. This is particularly important for bearing on light members, such as open-web joists, or cantilevered structural members. If the deflection of the structural frame is sensitive to the location or eccentricity of the connection, limits should be given. Consideration should be given to both initial deflection and to long-term deflection caused by creep of the supporting structural members.

A structural steel frame building presents different erection and connection problems from a cast-in-place concrete frame building. For example, structural steel beams, being relatively weak in torsion, compared to concrete, generally require that the load be applied directly over the web or that additional bracing be provided to resist the effects of torsion. Problems during erection with the rotation of steel beams may occur if they are not adequately braced. Also, when detailing connections of GRC panels to tall, slender steel structures with even loading, allowances must be made for sway and

movements due to sun or wind on one side or seasonal thermal expansion and contractions.

Final erection tolerances should be verified and agreed on before erection commences and, if different from those originally specified, stated in writing or noted on the erection drawings.

Appropriate field procedures should be followed to ensure accurate application of tolerances. The general contractor is expected, and should be required, to establish and maintain control points and bench marks in an undisturbed condition until final completion and acceptance of the project.

Non-cumulative tolerances for the location of GRC units are shown in **Table 10.3**.

These tolerances are guidelines only. Consideration should be given to the stated tolerances to ensure that they are applicable to a given project. Upon completion of GRC panel alignment and before other trades interface any materials with the GRC units, it should be verified that the GRC panels are erected within the specified tolerances.

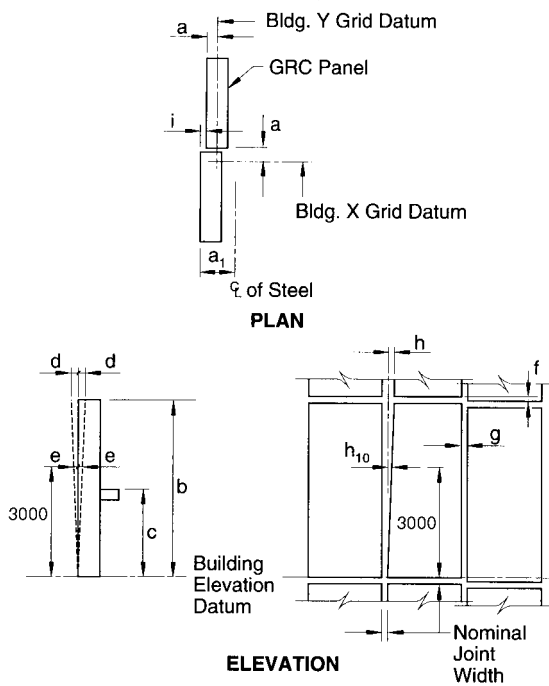
A nominal amount of bowing and warpage can often be removed during installation. Care should be taken to ensure that the GRC skin and the stud framing system are not overstressed when attempting to remove bowing and warpage. Limits to the amount of bowing that can be removed during installation should be established by the panel design engineer. Maximum permissible warpage of one corner out of plane of the other three corners should be 5 mm per m of distance from the nearest adjacent corner, or 6 mm total after installation. Bowing should not be greater than $L/360$ with a maximum of 25 mm, where L is the panel length in the direction of the bow.

Clearance is the space provided between adjacent members. It is one of the most important factors to consider in erection. The clearance space should provide a buffer area where frame, erection and product tolerance variations can be absorbed.

The designer should provide clearance space between the theoretical face of the structure and the back face of the GRC panel frame in detailing the wall and its relationship to the building structure. Adjacent materials may include products such as glass or subframes that are installed after the GRC panels are in place. If sufficient space is not provided, alignment of the wall as specified will likely result in delays and extra costs.

10.4

Table 10.3 Suggested erection tolerances



a	= Plan location from building grid datum ¹	± 13 mm
a ₁	= Plan location from centreline of steel ²	± 13 mm
b	= Top elevation from nominal top elevation:	
	- Exposed individual panel	± 6 mm
	- Non exposed individual panel	± 13 mm
	- Exposed relative to adjacent panel	± 6 mm
	- Non exposed relative to adjacent panel	± 13 mm
c	= Support elevation from nominal elevation:	
	- Maximum low	13 mm
	- Maximum high	6 mm
d	= Maximum plumb variation over height of structure or 30 m whichever is less ¹	25 mm
e	= Plumb in any 3 m of element height	6 mm
f	= Maximum jog in alignment of matching edges	6 mm
g	= Joint width (governs over joint taper):	
	- Panel dimension ≤ 6m	± 6 mm
	- Panel dimension > 6m	± 8 mm
h	= Joint taper maximum	9 mm
h ₁₀	= Joint taper in 3 m	6 mm
i	= Maximum jog in alignment of matching faces	6 mm
j	= Differential bowing as erected between adjacent member of the same design	6 mm

Notes: ¹ For precast framed buildings in excess of 30 m tall, tolerances 'a' and 'd' can increase at the rate of 3 mm per storey over 30 m to a maximum of 50 mm.

² For GRC elements erected on a steel frame, its tolerance takes precedence over tolerance on dimension 'a'.

The failure to provide adequate clearances is an all-too-common deficiency of cladding designs. They are absolutely essential for any of several reasons:

- To accommodate movement between adjacent members.
- To provide for possible size variation or misalignment.
- To provide working space to make the connection, eg sufficient room for welding or adequate space to use a wrench to tighten bolts.

The clearance between the structure and the GRC panel is an important detail and impacts the final appearance of the structure. Clearances should be reviewed during the design stages of the project to assure they are appropriate from both erection and aesthetic points of view.

The clearance necessary for erection of the GRC units will depend on their design, the dimensional accuracy of the building frame and other construction to which the GRC units are connected and the limits of adjustment permitted by the connection details.

The maximum variation from the specified clearance between adjacent independent members of separate building parts or components should be ± 6 mm. Adjacent independent members are members that are close together but are not connected structurally. These members may both be GRC and cast-in-place concrete, masonry, or steel. Typically, this clearance situation develops at an expansion joint or at the interface between a stair tower and a larger structure when the two are jointed only by an expansion joint.

All connections should be provided with the maximum adjustability in all directions that is structurally and architecturally feasible. To accommodate any misalignment of the building frame, connection should provide for vertical, horizontal, and lateral adjustments of at least 25 mm. Tolerance of hardware items cast into, or fastened to the structure should be ± 6 mm in all directions, plus a slope deviation of no more than ± 6 mm for the level of critical bearing surfaces. Connection details should consider the possibility of bearing surfaces being sloped or warped from the desired plane.

The minimum shim space between various connection elements should be 19 mm for steel structures or 25 mm for cast-in-place concrete structures with 38 mm preferred.

Where a unit is not erected within the tolerances of the connection design, the structural adequacy of the installation should be checked and the connection design should be modified, if required.

No unit should be left in an unsafe support condition. Any adjustments affecting structural performance, other than adjustments within the prescribed tolerances, should be made only after approval of the Engineer.

During panel installation, priority should be given to aligning the exterior face of the panels to satisfy aesthetic requirements. This will result in the interior panel frame face not being in a true plane. Panel design usually prevents spacing of the panel frame members from being co-ordinated with interior drywall modules. It is, therefore, recommended that, if the panel frame is to receive interior drywall or similar treatment, the interior finish should be mounted on shimmed transverse furring channels rather than directly to the panel frame.

A liberal joint width should be allowed if variations in overall building dimensions are to be absorbed in the joints. This may be coupled with a tighter tolerance for variations from one joint to the next for appearance purposes. It is apparent that the individual joint width tolerance should relate to the number of joints over a given building dimension. For example, to accommodate reasonable variations in actual site dimension, a 19-mm joint may be specified with a tolerance of ± 6 mm but with only a 5-mm differential variation allowed between joint widths on any one floor, or between adjacent floors. Alternatively, the jog in alignment of edge may be specified. The performance characteristics of the joint sealant should also be taken into account when nominating a joint size.

In a situation where a joint has to match an architectural feature such as a false joint, a large variation from the theoretical joint width may not be acceptable and tolerance for building lengths will have to be accommodated at the corner units.

10.4.4. Interfacing Tolerances

Interfacing tolerances and clearance are those required for joining of different materials in contact with or in close proximity to both before and after erection, and for accommodating the relative movements expected between such materials during the life of the building. Typical examples include tolerances for window and door openings; joints, flashing and reglets; mechanical and electrical equipment; elevators and interior finishes; and walls and partitions.

Fabrication and erection tolerances of other materials must be considered in design as the units must be co-ordinated with and must accommodate the other structural and functional elements making up the total structure. Unusual requirements or allowances for interfacing should be stated in the contract documents.

Where matching of the different materials is dependent on work executed at the construction site, interface tolerances should be related to erection tolerances. Consideration should also be given to provision for adjustment of the materials after installation. Where tolerances are independent of site conditions, they will depend solely on normal manufacturing tolerances plus an appropriate allowance (clearance) for differential volume changes between the materials.

A critical interface area is the connection between the GRC spandrel panel and the spandrel glazing system. The interface tolerance between these two systems is as shown in **Figure 10.5**.

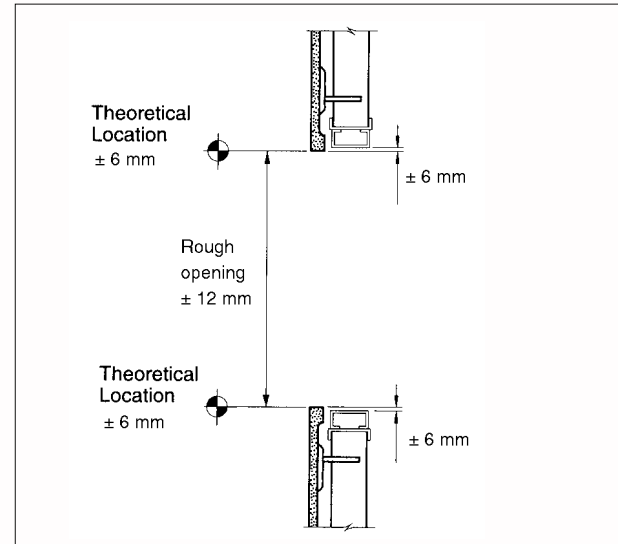


Figure 10.5 Interfacing tolerance

10.5 STANDARD PRODUCTS

A very large part of the GRC market is concerned with standard product. The following system should be adopted for contracts involving standard GRC products.

- 1 Manufacturer identifies available product by way of brochure.
- 2 Manufacturer obtains design certification for product from a chartered engineer experienced in GRC.
- 3 Proposed client identifies product. Client's engineer assesses design data supplied by engineer acting on behalf of manufacturer and ensures that assumptions of design are valid in proposed application. Alternatively the manufacturer's engineer can do this provided he has been given the opportunity to examine the proposed product application and the 'in-service' environment.

Referenced Documents

The following document was referred to in Chapter 10:

- *Precast Concrete Handbook* Published by National Precast Concrete Association Australia and Concrete Institute of Australia, September 2002.

11 HANDLING, ERECTION and INSTALLATION of PRODUCT

11.1 INTRODUCTION

Damage can be done to the product through unplanned movement. This starts at demoulding, handling during curing, packing for transport, transportation, installation, and adjustment on the building during final levelling. Written quality control procedures are required for each activity certified by the design engineer as being in accordance with his design requirements.

It is essential that the fibre to matrix bond is not overstressed at an early age. Such overstressing can be equivalent to reducing by as much as 50% the expected design life of the accelerated ageing program.

11.2 DEMOULDING

Various techniques of demoulding are available. Lifting by a crane is the most common. The Engineer must approve the location of lifting points and the age of lifting. Coupons should be made specifically to assess strength at lifting. This will vary from day to day depending on the climatic conditions. Very considerable loads can be generated if the 'suction seal' is not sensibly released.

The coupons should be stored with the GRC. Sandwich panels will require coupons for the face skin and also compression test cylinders for the core unless the lifting points attach directly to the bottom skin. Imposed stresses should be maintained at no greater than 50% LOP at that day. If such tests are not performed by the manufacturer, the Engineer should assess the stresses at demoulding and deduct them from his long-term allowable design strength.

Vacuum demoulding is to be encouraged for sandwich panels though one must be confident of skin-to-core strengths and also core tensile strength. Available correlation between compressive strength and unreinforced concrete tensile strength can be used to monitor stresses.

Rotational moulds are the preferred solution since they can place the product immediately on its minor loading axis. This is not always cost effective for very large panels. If not possible, then strict control and assessment of rate of gain of strength and lifting sequences is fundamental.

11.3 CURING

Once the panels are demoulded, they should be taken to the curing area in accordance with procedures approved by the Engineer. Soft-suspension trailers or similar with appropriately placed packing is the best way to ensure that stresses are controlled. If the Engineer feels unable to satisfy himself that panels have been properly transported, he should deduct induced stresses from his

long-term allowable stress. This is particularly important when panels do not have the design redundancy offered by a steel frame.

11.4 LOADING AND DELIVERY

GRC products are usually transported on tractors and semi-trailers. Rail or barge transportation may be feasible over long distances. The normal highway restrictions on weight and size will have to be observed. Due to their thin-wall construction, which reduces weight, GRC panels can offer significant cost savings in delivery, handling and construction loads.

Panel configurations should be developed that may permit nesting of the units.

The manufacturer should ensure that panels are ready for delivery before loading. This may necessitate a lead time for final checking, possible cleaning and minor repairing that may be required as a result of damage or accumulation of dirt in storage. Panels should not be shipped to job sites until they have reached sufficient strength to withstand the effects of the particular shipping and handling methods used.

Factors such as the size, shape, type of finish, method of transportation, type of vehicle, weather, and road conditions and distance of haul enter into determining the necessity of wrapping or protecting the GRC panels during shipment.

Panels should be loaded, as necessary:

- to permit their unloading for erection in proper sequence to minimise handling;
- with proper supports, blocking, cushioning, and tie-downs to prevent or minimise in-transit damage (not too tight but sufficient to prevent upward movement);
- with proper padding between GRC and chains or straps to preclude chipping of the GRC;
- to support the panels in a manner to minimise relative movement between the stud frame and the skin and transfer load evenly to the supporting vehicle tray.

The blocking points and orientation of the panels on the shipping equipment should be as designated.

GRC panels should be loaded so that the GRC skin does not support the weight of the steel frame without adequate blocking. This is generally achieved by blocking between the trailer bed and stud frame. As a general rule, the stacking of units atop each other should be limited to no more than 5 units.

All blocking, packing and protective materials should be of a type that will not cause damage, staining or other disfigurement of the panels.

Soft materials, such as high-density polymer, polystyrene, or elastomeric materials should be used to protect the panel edges during shipment. When tying down the GRC panels to the trailers, it is preferable to use nylon straps not chains. Special care is required to protect the panels at the binding points of the straps, and to protect against the 'slap' of a long-reach strap. Over tightening of straps must be avoided as this may result in cracking and permanent deformation of the panels. If the panels are 'nested' or stacked, consideration should be given to transfer of vertical load in order to prevent progressive crushing or other damage. Special support frames may also be used to prevent damage from occurring. Attention should be given to adequately supporting any top or bottom returns at the strapping points in order to avoid cracking of the GRC skin (see **Figure 11.1**).

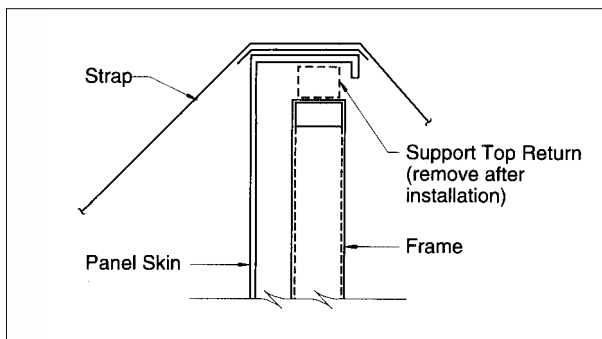


Figure 11.1 Recommended strapping procedure

The erection supervisor should co-ordinate the arrival of the panels at the job site for erection in a safe and proper manner.

All GRC panels should be clearly and individually marked as indicated on the erection drawings. Panels which require sequential erection should be so marked. Weight of the units should be communicated to transport and erection personnel.

Corners and panels with returns of unusual length are often shipped with edge-to-edge bracing which should not be removed until just prior to erection.

There are a variety of ways by which a panel may be hoisted into position. The type of erecting equipment is determined by the weight of the product and distance of reach to set the panel. If possible, panels should be unloaded by handling in a vertical position. All chains, binders, straps, bracing, packing and edge protection of the panels should be carefully removed prior to unloading. Panels should be lifted slowly from the transport vehicle. If any binding occurs during lifting, the obstruction should be removed. Panels should be handled to prevent structural damage, cracking or chipping. Groups of panels should not be removed with one lift unless designed accordingly.

Blocking between the panels should be free from the panel adjacent to it. Balance of the trailer should be maintained by unloading alternate sides of the vehicle or by blocking the trailer. The exterior panel should be unloaded first from a stack to minimise chipping and scraping. Panels should not be slid out from the middle of a stack. Site conditions should allow erection equipment and transportation units to proceed under their own power to a location where GRC panels can be handled by the erection equipment directly from the transport vehicle. If temporary job storage of panels is required, storage areas should be relatively level and firm, well-drained, and located where there is little chance of damage due to other construction activity.

In addition, site conditions, season of the year, and length of storage at the job site should be considered in determining the necessity of protection to prevent accumulation of dust, and other staining material from discolouring the panels. If a loaded trailer is stored at the job site, the shipper should carefully block the trailer to prevent damage to panels or accidental overturning. Particular care should be taken on storage areas constituted from 'fill' material. The stored trailer should be parked on firm level ground. If required, rotation of panels should be done while supported by the crane in the air and not accomplished by resting the panels on the truck or ground unless the panels are specifically designed for such stresses. Relatively flat panels should always be shipped on their edge. For unusually shaped panels, special erection rigs, such as rotating sheaves, spreader beams or specially designed lifting brackets should be used to avoid damaging the panels during hoisting and installation.

11.5 INSTALLATION

11.5.1 Cladding Panels – Co-ordination

An efficient job site operation is the result of planning between the manufacturer, carrier, erector, and the general contractor. A check of job site access for all necessary equipment is essential. A check of building frame tolerances and supporting surfaces will reduce delay. The manufacturer needs a sequence that will best utilise the available transport. The erector needs a steady supply of panels to ensure efficiency and job site progress.

11.5.2 Cladding Panels – Erection

Erection supervision requires knowledge about handling and positioning panels on the building; advance planning will ensure the presence of all necessary tools, equipment and loose connection hardware. Job site conditions must properly accommodate the erector's equipment operating under its own power. There is no substitute for advance field layout work to ensure horizontal and vertical control as the panels are positioned.

Generally, panels should move directly from truck to

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building to minimise the hazards and costs of extra handling. The erector should confer with the manufacturer on proper storage methods if they are not shown on the erection drawings.

The low weight of GRC panels permits lighter and less expensive handling equipment. A simple hoist, mounted on the roof or a small crane may be sufficient. Care is required during lifting since the lightweight GRC panels are more susceptible to wind effect than heavier concrete units.

The erector should understand the function and performance of each connection detail to ensure that panels are installed in keeping with the design concept; field modifications to the steel stud frame or connection system should be made only with the approval of the engineer responsible for the design. If connections require temporary support, such as shims, they must be removed as soon as possible so that the connection system functions in the manner intended. Field welding at temperatures below -7°C should be avoided due to the possibility of fractured welds.

A satisfactory installation results if the erector understands product manufacturing and erection tolerances coupled with permitted variations in building frame construction.

During panel installation, priority is given to aligning the exterior face of the panels for aesthetic reasons (see **Figure 11.2**). This may result in the interior stud face not being in a true plane. Panel design usually prevents stud spacing from being co-ordinated with interior drywall modules. It is, therefore, recommended that, if the studs are to receive interior drywall or similar treatment, the interior finish should be mounted on shimmed transverse furring channels rather than directly to the studs unless otherwise co-ordinated.

Window frames should be attached directly to the head and sill tracks of the steel stud frame (or a separate framing system). The window loads, both dead load and wind pressure, are supported by the stud frame and transferred through the frame to the panel connections attached to the structure. The window frame is shimmed by the glazier to its proper location and then screw attached to the steel stud frame.

The only contact between the window frame and the GRC skin is the joint sealant, allowing the skin to move and preventing undue restraint of the skin. The GRC skin can be expected to expand and contract up to 2 mm/m as a result of moisture and thermal effects. If this is ignored, restraint due to improper installation of the window frame may result in excessive restraint of the GRC skin, thus creating a possible future cracking problem. The sealant joint between the window frame and GRC skin also keeps the wall system weathertight.

Insulation, fire protection, electrical and telephone conduits may be placed in the wall cavity created by the steel stud frame. Insulation and other trade items are installed at the job site by other subcontractors.

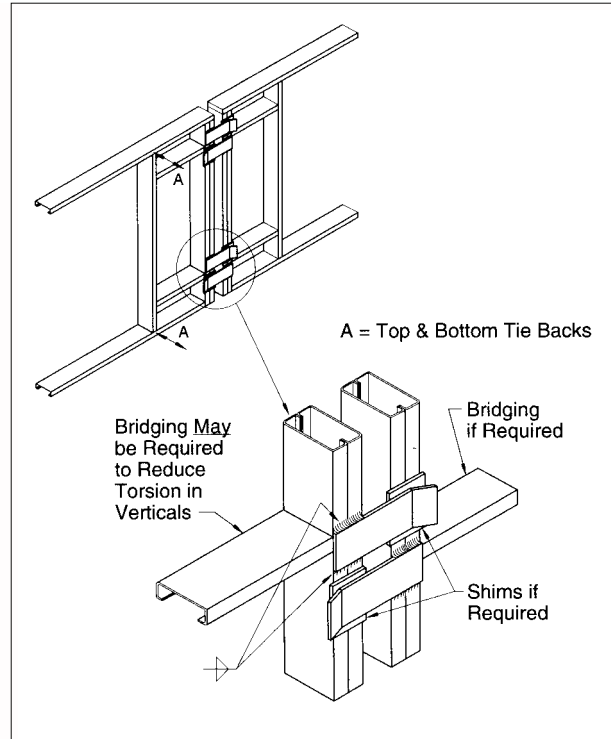


Figure 11.2 Alignment connections

11.5.3 Cladding Panels – Cleaning

Many GRC panel projects will require only spot cleaning with soap and water in isolated areas while other projects may require a general cleaning. More-stubborn dirt may require the use of a commercial cleaning compound or a dilute solution of muriatic acid. The GRC surface should be wetted in advance to prevent deep absorption by strong cleaners. A 3–5% phosphoric acid solution may be more effective on white or off-white surfaces and also helps to avoid a yellow stain. When using acids, special care is required in masking and protecting adjacent materials to avoid damage. A thorough rinsing with water after use of a strong cleaner is required to neutralise the panel surface.

11.5.4 Cladding Panels – Patching and Repair

Since GRC panels are inherently resilient and ductile, light in weight and highly resistant to crack propagation, there should be few chips and spalls resulting from storage, delivery, and handling. However, a certain amount of repair of product is to be expected as a routine procedure. Production blemishes should have been corrected at the plant. Since patching and repair of GRC is a specialised activity, it is recommended that the manufacturer's personnel be used for repair work since they are familiar with the use of bonding agents and shading or texturing techniques. It may even be necessary to prepare a composite patching mix reinforced with glass fibres. Damage that affects the structural capacity should be discussed with the design engineer. In general, the extent of patching and repairing required should be minor.

11.5.5 Cladding Panels – Joint Sealing

A joint will provide a degree of watertightness consistent with its design and exposure. In addition, the purpose, size and function of the building will also determine design requirements for the joint.

Design criteria for joints include:

- Amount of movement to be accommodated
- Architectural appearance
- Function of the building
- Exposure (orientation and climatic conditions)
- Economics.

The following decisions must be made in response to the design criteria:

- Width and depth
- Type
- Location
- Number
- Architectural treatment
- Materials selection.

Ideally, joint locations should be determined during the design development phase. Items affected by joint design are:

- Panel size and dimensional accuracy
- Weathering
- Tolerances
- Transition between adjacent materials
- Location of openings.

11.5.6 Cladding Panels – Width of Joints

Sealant life and performance are greatly influenced by joint width. Joints between GRC panels must be wide enough to accommodate anticipated wall movements. Joint tolerances must be carefully evaluated and followed if the joint sealant system is to perform within its design capabilities. If units cannot be adjusted during erection to allow for proper joint size, saw cutting may be necessary. When joints are too narrow, failure of the joint will occur, and adjacent units may come into contact with each other and be subjected to unanticipated loading, distortion, cracking and local crushing (spalling).

Joint width should not be chosen for reasons of appearance alone, but must relate to panel size, anticipated movement, building tolerances, joint materials and adjacent surfaces. The required width of the joint is determined by the temperature extremes anticipated at the site location, the movement capability of the sealant to be used, the temperature at which the sealant is initially applied, panel size and fabrication tolerance of the GRC units. All of these factors take precedence over appearance requirements:

- **Temperature Extremes and Gradients.** The temperature gradient used must reflect the differential between seasonal extremes of temperature and temperature at the time of sealant application. Concrete temperatures can, and normally will, vary considerably from ambient temperatures because of thermal lag. Although affected by ambient temperatures, anticipated joint movement must be determined from anticipated panel temperature extremes rather than ambient temperature extremes. Consideration should be given to the orientation of the wall surface in relation to the sun. In Australia, north-facing walls will experience significantly higher temperatures than south-facing walls.
- **Sealant Movement Capability.** The minimum design width of a panel joint must take into account the total anticipated movement of the joint (ie the GRC panels) and the movement capability of the sealant. All GRC is subject to volume changes from creep, shrinkage, and temperature variations.
- **Application Temperature.** A practical range of installation temperatures, considering moisture condensation at low temperatures and reduced working life at high temperatures, is from 5–32°C. This temperature range should be assumed in determining the anticipated amount of joint movement when designing the joints. A warning note should be included on the plans that, if sealing must take place for any reason at temperatures above or below the specified range, then a wider than specified joint may be required. Alternatively, changes in the type of sealant to one of greater movement capability or modifications to the depth-to-width ratio may be used to provide greater extensibility.

Many factors may be involved in actual building movement. These include, but are not limited to: mass of material, colour, insulation, building settlement, method of fastening and location of fasteners, differential heating due to variable shading, thermal conductivity, differential thermal stress (bowing), building sway, and seismic effects. Material and construction tolerances that can produce smaller joints than anticipated are of particular importance. Such tolerances should be considered in the design calculations and considerations.

The larger the panel, the wider the joint should be in order to accommodate realistic tolerances in straightness of panel edge, edge taper, and panel width. For example, with a typical one-storey panel 1500 mm wide, a joint width of 12 mm will accommodate tolerances suggested in Clause 10.4. With an 1800-mm panel, a wider joint is required.

Joints usually must accommodate variations in building dimensions so a liberal tolerance should be allowed for the joint widths. For example a 20-mm joint may be specified with a ± 6 mm tolerance. This tolerance should accommodate reasonable variations in the actual site

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dimensions. For reasons of appearance, tolerances covering differential joint widths for a floor or an elevation may be specified. In the previous example, joint width may range from 12–25 mm, but should be held to a differential variation of 6 mm. The joint width should then be specified as follows: 20 mm with a maximum 5 mm variation in width of adjacent joints. Alternatively, the jog in alignment of edge may be specified.

If the joint width determined is too wide, another sealant having a greater movement capability should be selected. For example, if movement capability is $\pm 50\%$, the joint width in the example becomes 20 mm.

To provide optimum quality for the installation and performance of field-moulded sealants, the architect should specify joint widths not less than 20 mm. Corner joints should be 25 mm wide to accommodate the extra movement and bowing often experience at this location. Narrow joints are considered to be a very high risk for any joint sealant installation.

The required sealant depth is dependent on the sealant width at the time of application. The optimum sealant width/depth relationships are best determined by the sealant manufacturer. Since manufacturers do not agree on the ideal proportion, generally accepted guidelines are:

- For joints from 12–25 mm wide, the sealant depth should be 12 mm. The sealant should have a concave shape giving greater thickness at the panel faces.
- For joints in excess of 25 mm wide, sealant depth should be 16 mm maximum and 12 mm minimum

The depth of the sealant should be controlled by using a suitable backup material. To obtain the full benefit of a well designed shape factor, the backup materials must also function as a bond breaker, **Figure 11.3**.

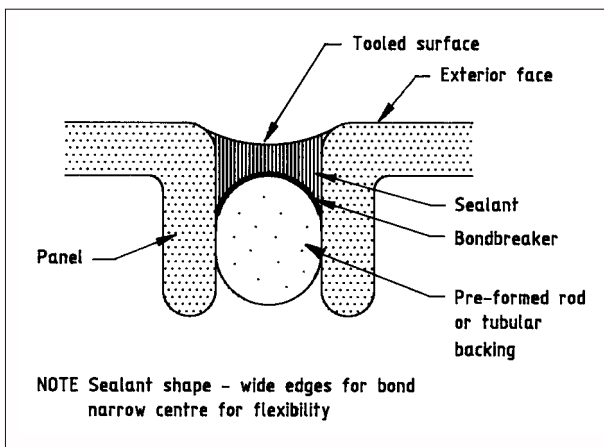


Figure 11.3 Ideal joint with field-moulded sealant

11.5.7 Cladding Panels – Materials for Joints

The most common joint materials are silicones which can accommodate up to 50% movement of their declared width (reference American ASTM C962).

The sealants used for specific purposes are often installed by different subcontractors. For example, the window subcontractor normally installs sealants around windows, whereas a second subcontractor typically installs sealants around panels. The designer must select and co-ordinate all of the sealants used on a project for chemical compatibility and adhesion to each other. In general, contact between different sealant types should be avoided.

The recommendations of the sealant manufacturer should always be followed regarding mixing, surface preparation, priming, application life, and application procedure. Good workmanship by qualified sealant applicators is the most important factor required for satisfactory performance.

The edges of the GRC units and the adjacent materials must be sound, smooth, clean, and dry. They must also be free of frost, dust, loose mortar or other contaminants that may affect adhesion such as form release agents, retarders, or sealers. It may be more economical and effective to prepare joint surfaces prior to erection if a large number of units require surface preparation. It may be desirable to conduct adhesion or peel tests to determine the compatibility of the sealant with the contact surfaces.

Also, before caulking, the joint should be wiped with a cloth dampened with an oil-free solvent such as xylol. Sometimes, smooth GRC has a 'skin' on the surface which may peel off leaving a gap between it and the GRC after the joint sealant has been applied. It may be necessary to remove the skin by using a stiff wire brush followed by a high pressure water rinse.

Backup materials help to shape sealants. When selecting a backup material and/or bond breaker, the recommendations of the sealant manufacturer should be followed to ensure compatibility. The backup should not stain the sealant, as this may bleed through and cause discolouration of the joint. Backup materials, should be of suitable size and shape so that, after installation, they are compressed to 30–50%. Proper selection and use of backup material is essential for the satisfactory performance of watertight joints. Length-wise stretching, twisting or braiding of the tube or rod stock should be avoided. When inserting a polyethylene foam backup rod, a blunt tool should be used to avoid skin puncture of the rod and possible out-gassing which may cause blistering of the sealant.

The principal functions of backup materials are:

- Controlling the depth of the sealant in the joint (provide proper sealant dimensions and shape).
- Serving as a bond breaker. This prevents the sealant from bonding to the back of the joint and exposing itself to three-dimensional stress or stress concentrations.
- Assisting in tooling of the joint.
- Protecting the back side of the sealant from attack by moisture vapours trying to escape from the building. Use of a second backup rod is recommended where high vapour pressure occurs at the immediate back surface of the sealant and should be placed at about 25% of the panel depth behind the first rod.

Primers may be recommended by the sealant manufacturer for the following reasons:

- To promote adhesion of sealants to porous surfaces or to reinforce the surface.
- To promote adhesion of sealants to surfaces such as porcelain enamel, unusual types of glass, certain metals and finishes, and wood.
- To promote adhesion of sealants to an existing surface treatment which is difficult to remove.

Special care should be exercised to avoid staining the outside face of the GRC unit since some primers will leave an amber-coloured stain if brushed along the surface. This stain will have to be mechanically removed which will be expensive. The primer should be allowed to cure before application of the sealant. The sealant and primer should always be supplied by the same manufacturer.

The following characteristics should be considered when making the final selection of sealants from those with suitable physical (durability) and mechanical (movement capability) properties:

- Adhesion to different surfaces – concrete, glass, aluminium, etc.
- Surface preparation necessary to ensure satisfactory performance – priming, cleaning, drying, etc.
- Serviceable temperature range.
- Drying characteristics – direct pickup, susceptibility to damage due to movement of joint while sealant is curing.
- Puncture, tear and abrasion resistance.
- Colour desired and colour retention.
- Effect of weathering – water and sunlight – on properties such as adhesion, cohesion, elasticity.
- Staining of surfaces caused by sealant or primer.
- Ease of application.
- Environment in which the sealant is applied.
- Compatibility with other sealants to be used on the job.

11.5.8 Joint Sealing

Opinions vary on the correct design of joints. The USA uses generally one-stage joints; Europe, two-stage joints. It is the responsibility of the client's representative to nominate whether he wants a one-stage or two-stage joint. Thereafter, the designer of the joint must assess carefully the capability of the proposed material in relation to cleanliness of surfaces, method of installation, weather protection.

11.5.9 Joint Sealing – Unsealed Joints

Overlap Joint – This type of joint should be designed according to existing criteria for fibre cement or other thin sheet materials.

Cover Strips – The upturn flanges of two adjacent GRC components are covered by an inverted channel of another material. This is essentially a version of the overlap joints and should be treated as such, since forming an air-tight seal can be difficult.

11.5.10 Joint Sealing – Sealed Joints

These types of joint are expected to resist the flow of air through a joint. All involve some method of sealing the joint to resist the air flow and hence require some material to be always in contact with the components on either side of the joint.

The contact is maintained by compressive forces or adhesion, but, in either case, the joint needs to be carefully designed with regard to the relative movement of the components in order to maintain the seal under all conditions.

Sealing Compound – Joints filled with sealant do not need complex edge details, but the surface must be clean, dry, free from laitence and primed according to the sealant manufacturer's instructions. Sealants must be flexible to allow for GRC movement and the joint design should anticipate this, ensuring that the expected joint movement in all three directions is within the capabilities of the sealant. For example a 3-m-long component may experience up to 6 mm moisture and thermal movement. Sealants are readily available which have an allowable strain capacity of 25%, so to accept a movement of 6 mm the joint width will need to be a minimum of 24 mm. In order to maintain this, it has been suggested that the joint width be designed to be:

Minimum allowable + expected movement, which in this case would be $24 + 6 = 30$ mm.

It is important that the design of the joint should take into account the component surface. Aggregate facing mixes can be porous, allowing water to penetrate behind the seal if wrongly positioned. Care must be taken to keep any applied finish clear of the sealing area since this could cause problems with adhesion. Joints filled with sealing compound properly applied and well designed can resist hydrostatic pressure.

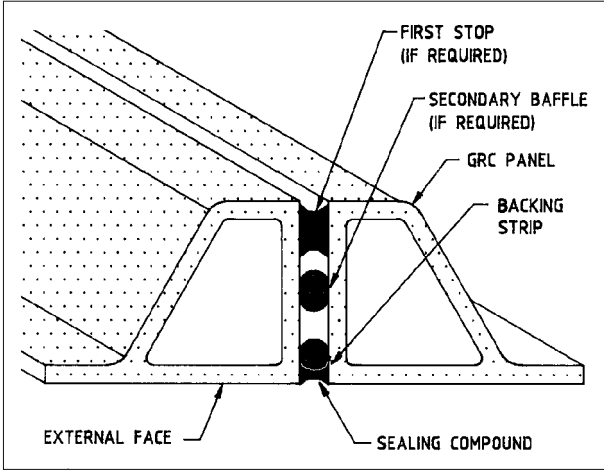


Figure 11.4 Sealing compound joint (butted)

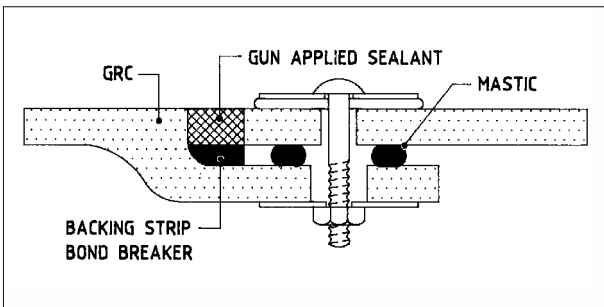


Figure 11.5 Sealing compound joint (lapped)

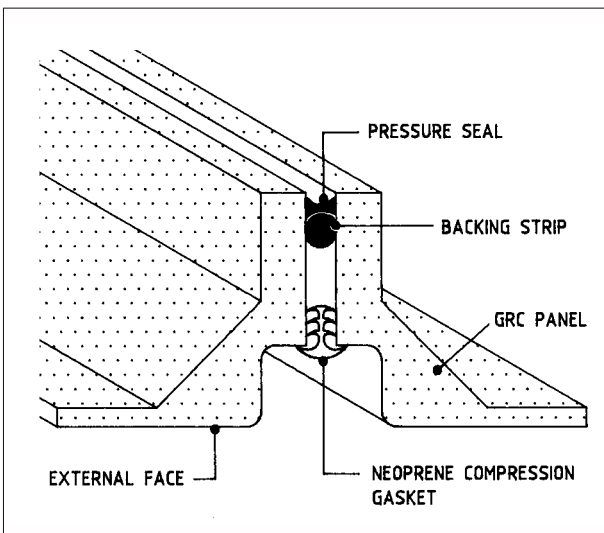


Figure 11.6 Gasket joint

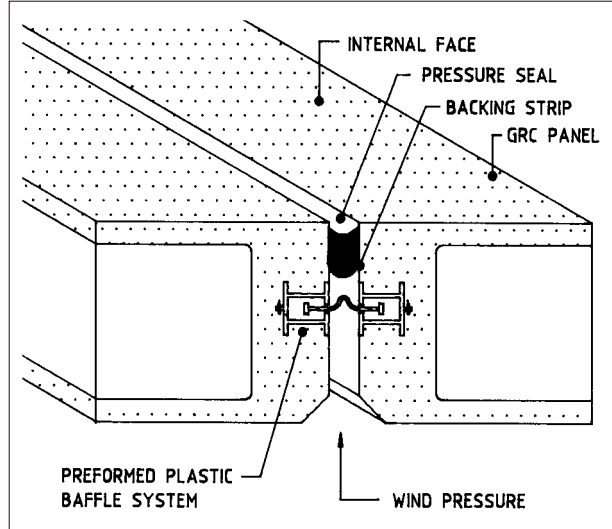


Figure 11.7 Gasket joint for small, flat areas of GRC

11.5.11 Gasket Joints

Gasket joints do not need complex edge details to components, but the surfaces to which they match must be very smooth, accurate and defect free. Gaskets rely on permanent compression to provide an effective seal, so very tight joint tolerances and close attention to GRC thermal and moisture movement is necessary for an effective gasket joint.

11.5.12 Open Drained Joint

This type of joint is suitable only for thick section GRC components with deep edge returns. It contains an airtight seal which is protected from direct weathering by the baffle. Although the baffle can accept considerable variations in joint width and considerable movement, the presence of the sealant at the back requires the joint width to be designed as if it were a sealant joint.

11.5.13 Compression Joints

This type of joint, where two flanges of GRC are bolted together with a layer of compressible material between, can be used only where no joint movement is expected and joint tolerances can be minimised. This type of joint will be capable of withstanding considerably hydrostatic pressure, although the joint detail around the bolt position is critical

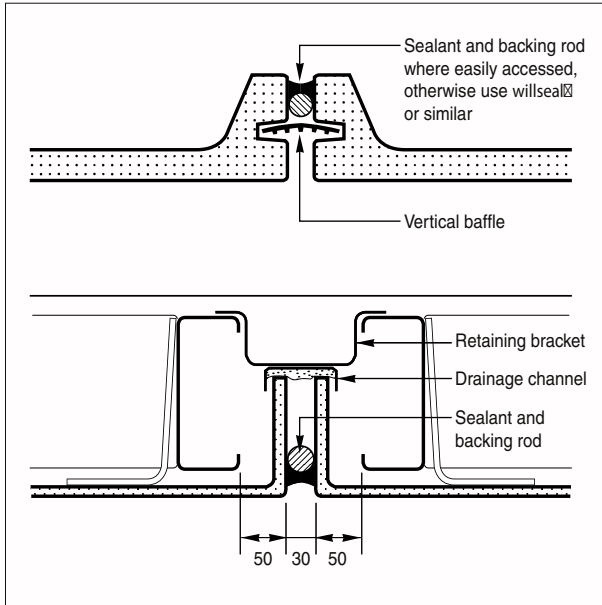


Figure 11.8 Open-drained baffle joint

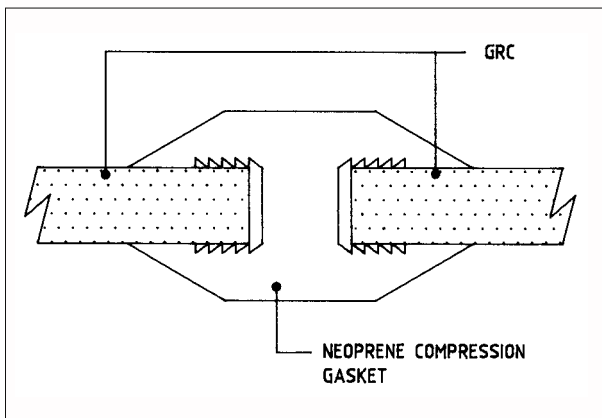


Figure 11.9 Compression joint

11.6 FIXINGS OF CLADDING PANELS TO BUILDINGS

11.6.1 Introduction

The method of fixing the panel must be clearly established in the design; the actual method used on site to connect the panels to the building must reflect the design assumptions.

The Engineer must nominate the anticipated movement of the panel, design for restrained movement if appropriate and ensure that the joints accommodate that movement. Further, he must allow for the actual movements of the building itself and ensure that such movement has no affect upon the panels.

11.6.2 Fixing Systems

Many types of fixing commonly used with concrete, stone, fibre cement, GRP or steel can be used directly or adapted to GRC, giving a wide range of possibilities.

In respect of the materials used for fixing components, GRC is not different to concrete and the choice of material is likely to be influenced by the Local Statutory Authority. Austenitic stainless steel and non-ferrous inserts, together with galvanised mild steel may be used. The galvanised coating weight will be dictated by the durability required. Unprotected mild steel must not be used under any circumstances for cast-in fixings. Where dissimilar metals are in contact there is a possibility of galvanic corrosion occurring. This can be avoided by the use of isolation materials such as neoprene and synthetic resin bonded fibres.

In all cases, the fixing system should be designed so that the force transmitted through the fixing is transferred to a sufficiently large area of GRC. For example the fixing should be encapsulated in a block of GRC, or oversize washers or plates should be used to spread the load.

The fixing system should make allowance for site and manufacturing tolerances, for thermal and moisture movement of the GRC, and for movement of the structure. For instance one fixing can be used to locate the product while all other fixings allow movement relative to it. (Figure 11.10). Because of the occurrence of bowing with sandwich construction products, fixing systems for these should not restrict small rotational movements and should not be placed in positions which restrict the bowing of the product.

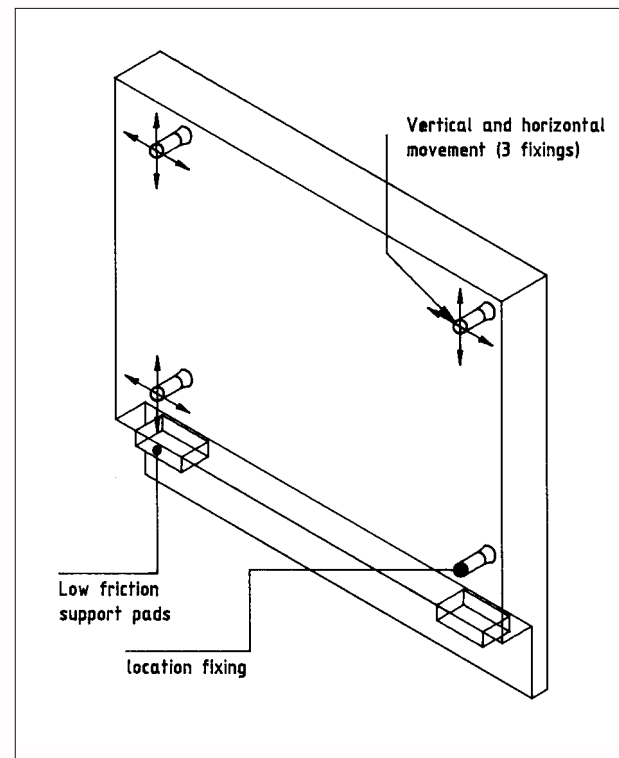


Figure 11.10 General principles of fixing for ribbed single-skin or sandwich panels (See Notes next page)

11.6

Notes to Figure 11.10:

- 1 Four attachments only per panel.
- 2 All fixings to allow rotational freedom.
- 3 Upper fixings restraint only; panel weight supported at base or by lower embedded fixings if appropriate
- 4 Ensure presence of floor screeds, slabs, partitions, fittings, etc does not prevent designed movement from taking place.

Allowance for movement cannot be achieved just by providing a slotted hole since a bolt system can not be tightened sufficiently to eliminate sliding in the bracket. Various methods of allowing movement with many types of fixings are shown below. The fixing detail should ensure that subsequent site work, eg screeding, is not allowed to lock fixings which are supposed to allow movement.

Where possible, products of significant weight should be supported from below so that the weight of the product induces compressive stresses, thus leaving the full tensile strength of the product available to resist applied loads.

The state of serviceability expected from the fixing should be considered and a factor applied accordingly.

A full set of instructions on the assembly and use of the fixings (including advised bolt torques) should be provided with the drawings.

Encapsulated Fixings - This type of fixing includes cast-in sockets and other major cast-in concrete fixings.

When used to carry high loads the fixing should be encapsulated in a block of good quality GRC with a minimum width of 100 mm and a minimum dimension of 50 mm between the fixing and the edge of the component. The detail of the fixing area should be such

that it is easily accessible during manufacture. Good quality material must be used around the fixing. Waste material is not acceptable.

Pull-out tests on encapsulated fixings in GRC show similar results to the same fixings used in concrete, **Table 11.1**.

Three suggestions for allowing freedom of movement with cast-in fixings are shown in **Figures 11.11, 11.12** and **11.13**, but any method of fixing capable of allowing in-plane translation in all directions, out-of-plate rotation and sufficient tolerance will suffice.

The principles of **Figures 11.11** to **11.13** also apply to cast-in channels or inserted fixings.

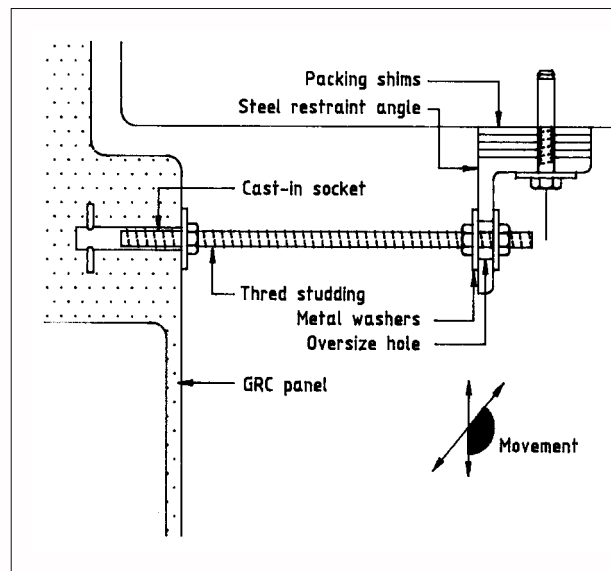


Figure 11.11 Flexible rod

Table 11.1 Results of pull-out tests on some types of cast-in sockets

Type	Illustration	Test method	Brand tested	Size	Pin (mm)	Pull-out load (kN) for length (mm)		
						38	50	75
Cast-in sockets - cone type. Ferrous and non-ferrous			Harris & Edgar	M10	-	25	25	30
			HET 300 series	M12	-	-	30	50
			Aluminium bronze	M16	-	-	30	60
Cast-in sockets with cross-pin anchor bar. Ferrous and non-ferrous		As above	Harris & Edgar	M10	6 ϕ x 50	Insufficient data, but		25
			HET 27 series	M12	10 ϕ x 75	expected to be		50
				M16	10 ϕ x 75	similar to cone type above		60
Cast-in socket nut encased in plastic		As above	Fischer BM12	M12	-	-	-	40

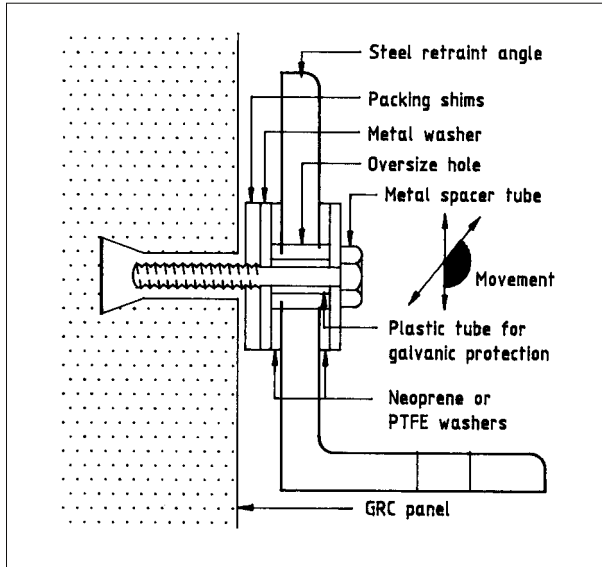


Figure 11.12 Sliding bracket

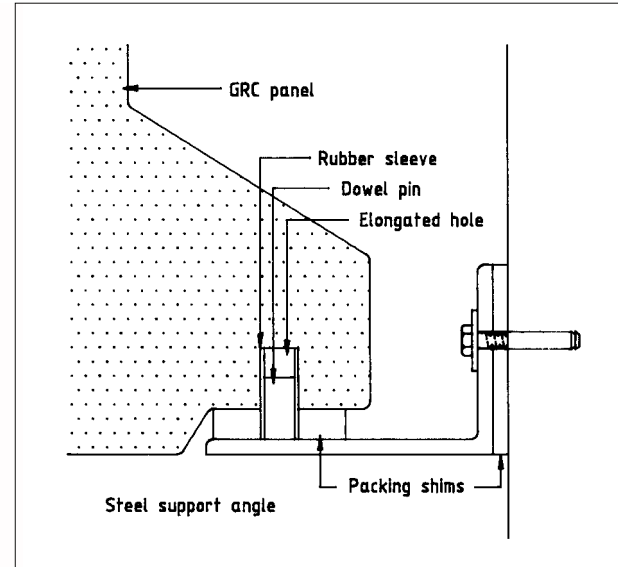


Figure 11.14 A dowel-type fixing

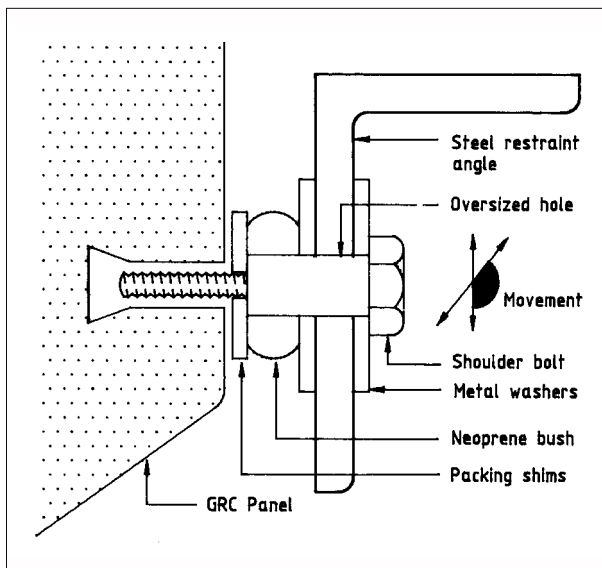


Figure 11.13 Resilient bush fixing

Cast-in Channel Fixings – If these are well incorporated, the loading values for concrete panels can be used, but it would be advisable to perform pull-out tests on an actual GRC component.

Inserted Fixings – This type includes expansion bolts and chemical anchors. These are not recommended for heavy-duty fixings in GRC because of variability in test results.

Dowel Pin or Dowel Plate (Corbel) Fixings – If correctly detailed this system can allow for any amount of in-plane movement and tolerance, but at the same time gives ease of attachment with high resistance to lateral forces. This type of fixing should be designed for the dowel pin shearing through the GRC walls of the socket.

Glazing Systems – Any system which is satisfactory for the fixing of glass will be satisfactory for flat sheet GRC of the same edge thickness.

A/C Fixings – All fibre cement fixings can be used for fixing single-skin GRC. Pull-through shear stresses should be checked.

Oversize Washers – Any form of fixing through the panel can be used with an oversize hole in the GRC and oversize washers or bearing plates to spread the load, eg nails, screws, bolts, pop rivets, blind fixings.

The washer should be at least 5 times the diameter of the fixing mechanism and of sufficient thickness ($> \frac{1}{16}$ washer diameter) to spread the load effectively. Tests have shown that the fixing can then be designed to the shear stress acting around the perimeter of the washer. Where bolts are used, tightening torque should be limited to avoid locking the fixing by distorting the oversize washer.

Cast-in Studplate – This type of fixing is similar to a cast-in washer, but has a stud welded to it. The same comments apply.

Screw Fixing – For minor fixings, screwing directly to the GRC can be a suitable method of attachment. This can be done using:

- Self tapping screws into pilot holes. Good attachment depends critically on the choice of pilot hole diameter.
- Screws into masonry plugs.
- Screws into cast-in plastic block. Wood blocks can be used, but may swell with moisture during casting and curing of the GRC, subsequently shrinking away from the surrounding GRC.

Adhesives – Adhesives suitable for cement-based materials can be used with GRC and will give joint strengths similar to those obtained with other cementitious substrates.

11.7 TOLERANCES FOR ERECTION

Manufacturing interfacing and erecting tolerances must be taken into account during the design phase of each project to ensure satisfactory panel installation. Erection tolerances are those required for realistic fit with the building structure. Erection tolerances are determined by the characteristics of the building structure and site conditions and are provided to achieve uniform joint and plane wall conditions. They should be determined on the basis of individual unit design, shape, thickness, composition of materials, and overall scale of the unit in relation to the building. The specified erection tolerances affect the work of several trades and must be consistent with the tolerances as specified for those trades. Where GRC units connect to site work, such as footings or foundation walls, ample erection tolerances are required.

Final erection tolerances should be verified and agreed on before erection commences and, if different from those originally specified, stated in writing or noted on the erection drawings.

Appropriate field procedures should be followed to ensure accurate application of tolerances. The general contractor is expected, and should be required, to establish and maintain control points and bench marks in an undisturbed condition until final completion and acceptance of the project.

Consideration should be given to the stated tolerances to ensure that they are applicable to a given project. Upon completion of GRC panel alignment and before other trades interface any materials with the GRC units, it should be verified that the GRC panels are erected within the specified tolerances.

A nominal amount of bowing and warpage can often be removed during installation because of the flexibility of GRC. Care should be taken to ensure that the GRC skin and the steel framing system are not overstressed when attempting to remove bowing and warpage. Limits to the amount of bowing which can be removed during installation should be established by the panel design engineer. Maximum permissible warpage of one corner out-of-plane of the other three corners should be 5 mm/m of distance from the nearest adjacent corner, or 6 mm total after installation. Bowing should not exceed $L/360$ with a maximum of 25 mm, where L is the panel length in the direction of the bow.

The clearance between the structure and the GRC panel is an important detail and impacts the final appearance of the structure. Clearances should be reviewed during the design stages of the project to ensure that they are appropriate from both erection and aesthetic points of view.

The GRC panels should be located in the centre of their theoretical location on the building and adjusted to accommodate adjacent panels, proper joint width, and other adjacent materials.

11.8 INSPECTION AND ACCEPTANCE

All chipping, blemishes or other damage occurring at the site should be reported to the erection supervisor.

The manufacturer, if responsible for erection, should make a thorough inspection of the GRC installation after erection and arrange for final repairs, cleaning if required, readiness for other trades such as caulking, window installation, glazing, etc, and for acceptance by the architect.

11.9 CLEANING

Dirt and stains which occur during the shipping and erection processes should be cleaned by the manufacturer or erector, as necessary. Cleaning should be performed no earlier than three days (or as nominated for curing of the repair material) after any GRC skin repairs have been completed. The manufacturer should be consulted regarding cleaning procedures. Before cleaning, a small (0.8-m²) inconspicuous area should be cleaned and checked to determine the suitability of the cleaning agent and method prior to proceeding with the cleaning process.

11.10 SURFACE COATINGS

Sealers or clear surface coatings should be tested on reasonably sized samples of varying age, and their performance verified over a suitable period of exposure or usage based on prior experience under similar exposure conditions. Sealers should be applied in accordance with the manufacturer's written recommendations. Any sealer used should be guaranteed by the supplier or applicator not to stain, soil, darken or discolour the finish. Also, some sealers may cause joint sealants to stain the panel surface or affect the bond of the sealant. The manufacturers of both the sealant and the sealer should be consulted before application, or the materials specified should be pretested before application.

See also Chapter 12 *Surface Finishes*.

Referenced Documents

The following document was referred to in Chapter 11:

- ASTM C962 *Guide for Use of Elastomeric Joint Sealants*. ASTM Philadelphia PA

Further Reading

Code of Practice for Safe Erection of Precast Concrete Cladding. Architectural Cladding Association, 1992. (60 Charles Street, Leicester LE1 1FB, UK)

12.1 INTRODUCTION

See Chapter 5 for coverage of the relationship between manufacture and surface treatments.

12.2 MODIFICATION OF THE SURFACE TEXTURE

12.2.1 Textured Moulds

The cement/sand slurry matrix of GRC has a very fine particle size and hence can accurately reproduce the characteristics of the mould surface against which it is produced. However, the extent to which the glass fibre is able to penetrate surface detail depends on the scale of the detail and the type of glass used. Note that the surface layers of a heavily textured panel may consist of unreinforced cement/sand mortar. It is therefore important that such layers are not included in the thickness of the component for design purposes.

If GRC is produced against very smooth surfaces a 'glass-like' finish can be obtained but this tends to accentuate small surface defects, give a patchy appearance when used in large areas, and tends to weather badly. This can be avoided by the use of finishes such as 'Bonnflon' but requires a high level of quality control.

Alternatively, use can be made of the natural roughness of plywood or timber in the mould to give a smooth but slightly matt finish. A much coarser texture can be produced using suitably prepared moulds.

In common with other cement-based products, cement-rich areas of GRC surfaces may suffer micro-cracking (crazing). Microscopic examination has shown that such micro-cracks normally travel no further than the nearest fibre and hence do not significantly impair the long-term performance of the component. Crazing can be eliminated or considerably reduced by:

- minimising the thickness of any unreinforced cement/sand mist coat on the component surface;
- increasing the aggregate content in the matrix coat, eg 2 parts sand:1 part cement;
- the use of an acrylic polymer.

The visual effect of crazing can be reduced by using a coarse surface texture. The texture coat thickness should be additional to the designed thickness of the GRC.

12.2.2 Post Treatment Processes

The 'as cast' surface of a GRC component can be textured by:

- acid etching, eg using hydrochloric acid;
- light sand or gritblasting in a similar manner to concrete;

- the use of retarding systems on the mould face, ie solutions, papers;
- polishing, in a manner similar to that used in precast concrete manufacture.

The finishing treatments should not be aggressive enough to penetrate into the GRC, exposing fibres at the face.

Skill is needed in applying these treatments and care must be taken to ensure that the required minimum component thickness is retained after treatment.

12.2.3 Aggregate Facing Materials

Aggregate facing materials are, in general, inorganic based. Inert aggregates, eg crushed rocks, gravels and sands, are bound with various cement types, including general purpose portland, general purpose blended, white and off-white cements.

The 'exposed aggregate' finish is widely used in the architectural precast concrete industry and, subject to certain limitations on aggregate size, similar techniques can be used on GRC panels.

Three basic methods are available:

- Sprinkling or placing aggregate on to the still-plastic matrix upper surface and tamping-in to achieve a mechanical bond, followed by brushing off excess aggregate when the panel is cured.
- Placing a layer of aggregate on the face of the mould before spraying up the panel. Larger aggregate can be placed in a sand bed to control the depth of embedment.
- Mixing the aggregate with cement, sand and water to form a 'concrete' render and coating a layer of this on the mould surface prior to spray up (face-down technique) or on the top face of the panel after spraying (face-up technique). In the face-down technique, a set-retarding liquid or paper can be placed on the mould surface prior to casting of the concrete and, after demoulding, the retarded matrix is brushed or washed off to expose the aggregate to the required depth (determined by the type of retarder used).

The latter method can also be used in the face-up technique. At an optimum time in the stiffening process the aggregate can be exposed by brushing or washing off the partly stiffened matrix to the required depth of exposure.

Alternatively, the concrete can be allowed to cure normally and the aggregate exposed by acid etching or sand blasting.

Most of these techniques have been successfully used in the production of GRC panels and, in general, the factors which affect the quality of such finishes on precast concrete also apply to GRC. However, the following factors should be borne in mind:

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- The sprinkling/placing techniques should be limited to very small aggregate since penetration of the GRC face occurs and this will affect the panel strength.
- The recommended maximum aggregate size for use with GRC is 12 mm, to fully utilise the low-weight, thin-section characteristics of the material.
- Aggregate facings can substantially increase the weight of a panel and this must be allowed for in both panel design and the design of fixing and lifting sockets.

All cement-based materials, including GRC, are subject to 'moisture movement' in that they expand during water uptake and contract when drying. One effect of this phenomenon is that if one face of a GRC component is covered with a facing material which prevents the expansion or contraction of the substrate due to moisture movement, or causes a difference in the rate of moisture change between the faces, then bowing of the component can occur. This may appear soon after removal of the panel from the mould but even a panel which is apparently flat at this stage may show bowing later. Consideration should therefore be given to this at the design stage.

Following curing, it is recommended that both panel faces be allowed to dry out at a comparable rate.

12.3 APPLIED FINISHES

The following properties are important in determining the suitability of applied finishes for use on GRC:

- Resistance to alkalinity
- Moisture compatibility
- Moisture vapour permeability
- Ability to cover rough and/or porous surfaces
- Weathering characteristics
- Mechanical flexibility
- Special knowledge or equipment required
- Renewal problems.

Particular care should be taken in the use of finishes having low moisture vapour permeability characteristics, which can introduce the following problems:

- Moisture already present in the panel or entering from the back face may migrate to the paint/GRC interface where it is unable to escape and may cause bubbling or flaking of the finish.
- In sandwich panels, the presence of a very low permeability film on the outer face greatly increases the risk of interstitial condensation.

These problems can be minimised by taking the following precautions:

- Ensure that the panel is as dry as possible before painting (below equilibrium in fact).
- Seal the back face of the panel with a material of similar or lower permeability.

Applied finishes, which are essentially organic based, cover a wide range of chemical types, and can be summarised as follows:

Type 1

These are frequently used, high moisture vapour permeable (breathable) systems. They are mainly water-based synthetic latex emulsions such as PVA co-polymers, acrylic co-polymers, styrene acrylic and styrene butadiene rubbers (SBR).

Care must be exercised in preparation of the GRC substrate before coating, including removal of friable material (laitance) and any residual mould release agent.

Emulsions are also available which contain a high percentage of fine quartz or stone granules, giving textured or exposed aggregate facings.

Type 2

These are usually in a solvent carrier and dry by an oxidation and polymerisation process, eg alkyd resin-based gloss paints.

For satisfactory use of this type of coating, primers should be alkali resistant and GRC surfaces should be allowed to condition at ambient temperatures until relatively free from water, as the coatings exhibit low vapour permeability characteristics.

Type 3

These are the most complex and include the two-part epoxy and urethane types.

Properties include excellent resistance to chemicals, water, UV and abrasion. Great care must, however, be exercised when using the systems on GRC. They possess low moisture permeability characteristics and in practice are difficult to handle because of the criteria necessary in mixing individual components and the preparation of the GRC substrate prior to application.

Coatings of this nature should be considered only when the requirement is to resist the most aggressive exposure conditions.

12.4 CEMENT-BASED PAINTS

These are generally based on white portland cement and are available in a range of colours. They contain special additives to facilitate application and to render the coating water repellent. They are supplied in powder form for mixing with water on site.

12.5 COLOURED CEMENTS

The available colour range for portland cements in Australia is grey, off-white and white. Grey cements have a variety of shades determined largely by raw material characteristics. Cement manufacturers provide a guarantee of colour control/uniformity for white and off-white portland cement.

12.6 OXIDES

Integral colour can be introduced into the cement/sand matrix by the use of oxide pigments.

It must be remembered that the cement component is itself a major colouring agent and will modify the oxide colour. Consequently, when using a grey cement the most satisfactory oxides are the earth tones of blacks and browns.

To achieve pastel colours an off-white or white cement must be used together with a light-coloured sand.

Synthetic oxides are generally preferred to mineral oxides, giving greater colour intensity. The use of integrally-coloured GRC requires a high level of control and manufacturing skills, to avoid localised discolouration. Its use should be confined to relatively small surface areas when smooth finishes are required. Larger panels will benefit from the use of false joints, ribs and textures such as those offered by form-liners. Blending the matrix with small amounts of oxide in the order of 0.5–1.0% (by weight of cement) is advisable when exposed aggregate finishes such as achieved by water-washing, sand-blasting or polishing are specified.

Points to consider include:

- All materials should come from the same source to avoid variation of colour.
- Only quality oxides should be used, ideally from the same colour batch.
- Cheaper oxides often have less colour intensity, ultimately requiring a greater oxide content.
- Care is necessary in weighing and batching the oxide.
- The uniformity of the curing regime for the entire project must be rigorously maintained.

12.7 SUMMARY

Coatings affect both the moisture content and temperature of the GRC. Both characteristics can affect the design of the product since temperature and shrinkage is of major concern in the design of GRC. Both these characteristics are affected by the application, eg GRC product in an internal environment has a different set of criteria than when used in an external application.

12.7.1 Application of Coatings

The generally accepted rule for GRC is to reduce the moisture content of the material down to around 5% prior to coating and then seal each face with a coating of similar permeability.

12.7.2 Uncoated GRC Aggregate Finishes

Post-cured applied finishes, even if cementitious, affect permeability and to a lesser extent the rule for coatings applies. If the GRC is a natural finish with or without pigment, then the designer must work on 'soaked' GRC design strengths.

12.7.3 Delamination

Long-term weathering involves cyclical wetting and drying. All product of any size should be subject to accelerated age testing in order that the laminar shear stresses can be assessed to ensure adequacy.

12.7.4 Sandwich Panels

GRC sandwich panels are a science all of their own, see Chapter 7 for manufacturing guidance. The coatings are the fundamental design aspect of the panel.

Internal moisture within the panels should be reduced to less than 7% prior to erection. Thus, if the panels become heated, it is unlikely that moisture vapour pressure will blister the coating. The panels should be sealed front and back once the moisture is lowered to stabilise the GRC.

GRC face skins should be manufactured on a very strict $-0, +3$ mm tolerance basis which means that the target thickness in manufacture will need to be higher than design, particularly for the non-mould face. Prefabricated panels where preformed faces are glued to a core may not require such control but recommendations regarding cores still dominate.

Full-scale model testing with accelerated ageing is very relevant in order that the calculated bow characteristics of the panel calculated (see Fordyce & Wodehouse referenced at end of Chapter 8) can be validated and the movement accommodated in the fixings.

Note: It is difficult to accelerate the ageing of a full-size panel. Calculation of the bow should be adequate if the procedure in the Cem-Fil design example is followed.

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13 VIBRATION-CAST GRC

13.1 INTRODUCTION

A large amount of GRC is used to produce standard products. Much of that product is produced by vibration casting.

In Chapter 9.0, specific reference is made to the assessment of the product.

In Chapter 8.0, design is covered in the same way as spray GRC. Values tend to be less than spray GRC because glass content tends to be nearer 3% rather than 5% by weight. However, strength is a function of mix design, quality control procedures and geometry of product and it is important that the fibre orientation and degree of compaction achieved in manufacture is reflected in design.

13.2 SCOPE

This Chapter provides information on GRC produced by the premix and vibration-cast method and indicates where it differs from sprayed GRC, which is the primary material concerned with in this Recommended Practice.

This Chapter covers only those aspects in which premix GRC and sprayed GRC differ. It covers the basic techniques for manufacture and provides guidelines on mix design, mould design and properties.

13.3 GENERAL DESCRIPTION

Premix GRC is the term applied to composites produced by blending alkali-resistant glass fibre into a sand/cement slurry. The wet slurry is placed and vibrated, into a mould, a technique similar to that used for precast concrete products. The vibration-casting process is relatively simple to control and mechanise. It is capable of producing items with good dimensional control, while complex components can be produced with relative ease. The process has low material losses together with accurate and reproducible control of product weight.

Alternatively, the fibrous mix can be sprayed.

13.4 HISTORIC DEVELOPMENT

Following the development of the sprayed process for GRC, it became apparent that, for small decorative repeatable units, the sprayed process was not suitable or necessary. In the mid-70s the process of vibration casting of premixed GRC was developed.

13.5 APPLICATIONS AND ADVANTAGES

Premix GRC is used in units where strength is not the prime requirement and productivity and decorative features combined with lightweight characteristics are more important. Consequently, it is frequently used for smaller, highly sculptured pieces such as architectural components and, at the other extreme, low-cost, standard products.

13.6 MATERIALS

Materials for use in the manufacture of premix cast GRC products should conform to the requirement set out in Chapter 4 with the exception of the following.

13.7 GLASS FIBRES

Only high-zirconia (minimum 16%) alkali-resistant glass fibres specifically designed for alkali resistance and use in concrete should be used. Specifically, 'E' glass, the type designed for use in the reinforcement of plastics, should NOT be used.

Fibre lengths of 12–19 mm are most common when using pre-chopped fibre, although specialist processes may use longer fibres. Fibres normally used for spray-up production are not normally suitable, being too soft and prone to tangling.

Alkali-resistant glass fibres constructed in other forms, ie randomised mat, can also be used in special circumstances.

13.8 PHYSICAL PROPERTIES

The physical properties of premixed GRC composites depend heavily on fibre content, fibre length and quality of mixture. They are also greatly influenced by the type of manufacturing process.

The following discussion refers to a composite made with alkali-resistant glass fibre.

13.8.1 Factors Affecting Properties

Basically, the same parameters govern premix properties as sprayed GRC, namely:

- Fibre content
- Fibre length
- Fibre orientation
- Composite density
- Sand or filler content
- Water/Cement ratio
- Quality of cure of composite
- Admixtures.

As with sprayed GRC, strength properties, such as flexural, tensile and impact strengths increase with increased fibre content and length. **Figure 13.1** shows how these properties vary.

As a general rule, premix with the same fibre content and fibre length will have lower physical strengths than will sprayed GRC. Reasons for this are:

- Premixing tends to entrap more air, thereby reducing the density of the composite. Strength of GRC is density sensitive.
- The mixing actions tends to cause filamentising and reduce strand efficiency.
- The spray process tends to lay the fibres down with almost perfect random placement orientation, or two-dimensional orientation, whereas premix will have a more three-dimensional orientation. This reduces the effective fibre content in the plane of the composite, thereby reducing the inherent strength of those plain or related strengths such as MOR and tensile strength.

Chapter 8 covers the primary and secondary properties used for design and is applicable to premix GRC.

13.8.2 Flexural Strengths

The effect of ageing on the ultimate flexural strength (FU) of premix GRC is very different to that of sprayed GRC. There is little difference between the EFU (early) and AFU (aged) with time.

This is due to the fact that young GRC does not fully utilise the strength of the alkali-resistant fibres because of their short length. With ageing, the mechanical bond between the strand and the cement matrix improves, enabling the reduced strand strength to be used more efficiently and thus producing an approximately stable FU even after ageing. However, care must be taken since the values are lower than sprayed material and yield strength is very similar to the ultimate strength, which is important in design.

13.8.3 Impact Resistance

As for the sprayed material, the impact resistance of premix GRC is affected by quantity and type of fibre used and is related to the area under the stress/strain curve.

Because of the shorter fibres and the lower percentage used, the impact resistance of premix is not as high as sprayed products but it can, nonetheless, be classified as a high impact material, see **Figure 13.1(b)**.

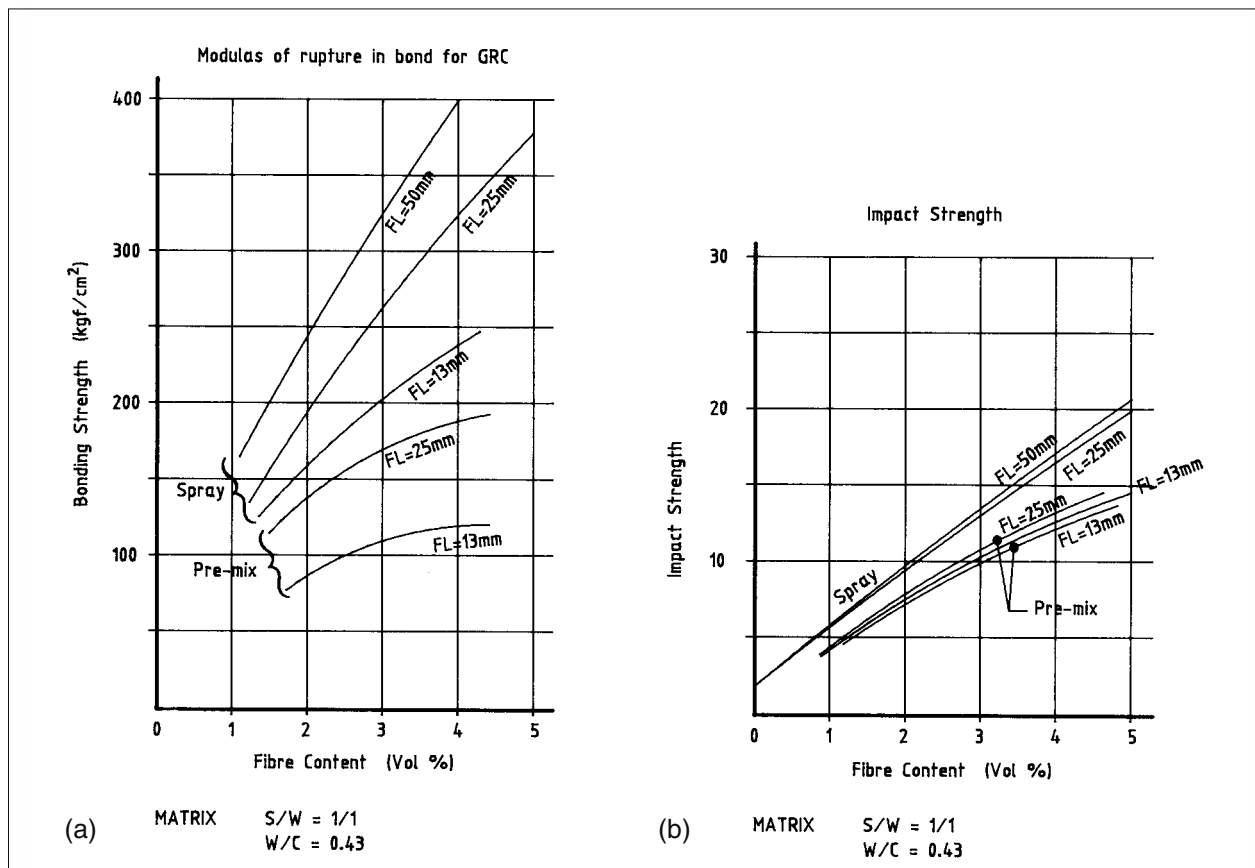


Figure 13.1 Strength of GRC made by various production methods

13.8.4 Property Summary

Different manufacturers may achieve different ranges of values of physical properties of GRC. Specific values of properties should be supplied by the manufacturer to the designer. For general information, **Table 13.1** gives ranges of 28-day property levels which should be attainable by competent operators using sand:cement ratios of between 2:3 and 1:1 and predicted 50-year aged properties.

Most other properties such as compressive strength and shear are lower than those obtained by the spray-up method, reflecting the lower fibre content.

Table 13.1 Typical range of premix GRC properties¹

Property	28-day, (E)	Aged ² , (A)
Density, dry (kg m ³)	1800-2000	1800-2000
Impact strength, charpy (Nmm/mm ²)	8-15	4-5
Compressive strength, edgewise (MPa)	40-60	50-60
Flexural:		
Yield, TY (MPa)	5-8	7-10
Ultimate strength, FU (MPa)	10-14	10-14
Modulus of elasticity (MPa)	10 x 10 ³ -20 x 10 ³	18 x 10 ³ -22 x 10 ³
Direct Tension:		
Yield, TY (MPa)	4-6	4.5-7
Ultimate strength, TU (MPa)	4-7	4.5-8
Strain to failure (%)	0.1-0.2	0.03-0.06
Shear:		
Interlaminar In-plane (MPa)	Not available 4-7	Not available 4-7
Coefficient of thermal expansion, (x 10 ⁻⁶ /°C)	10-18	10-18
Thermal conductivity (W/m·°C)	0.5-1.0	0.5-1.0

NOTES: ¹ These are typical values and are not to be used for design or control purposes. Each manufacturer must test production composites to establish physical properties for design. The values achieved in practice will be dependent on mix design, quality control of materials, fabrication process and curing.

² Developed from accelerated testing programs on GRC specimens immersed in 50-80°C. water. On the basis of comparisons between behaviour in real weather and accelerated tests, predictions can be made of properties for 50+ years in different climates.

13.9 DESIGN

Current design procedures for premix GRC follow those procedures presented in Chapter 8.

13.10 TOLERANCES

See Chapter 10.

13.11 MANUFACTURE

13.11.1 Product Manufacture

GRC Premix products should be obtained from manufacturers who possess a demonstrated capability to produce products of reliable and consistent quality.

These manufacturers must show that they have the required physical plant and equipment, experienced production personnel and the QC procedures necessary to manufacture products of a given size, with performance characteristics as designed, and at the required rate of production.

13.11.2 Plant Facilities

These are the same as discussed in Chapter 5 except for the following:

- Equipment for mixing the cement/sand slurry at high speed and the facility to blend the chopped strands at a lower speed to avoid fibre damage. Alternatively, proprietary mixes designed specifically for premix can be purchased.
- Means of vibrating the cast item to levels between 3000-9000 rpm or correct equipment to spray the fibrous premix into a mould.

13.11.3 Forms/Moulds

The design of the form should be co-ordinated with the manufacturing and installation requirements, in conformance with the product performance specification.

Due to the wide variety of end-use applications, with premix GRC the material becomes more dependent upon the quality and workmanship of the form. Premix GRC will repeat the most intricate design of shape of texture yet can also repeat flat, featureless units. The following is a general guide to materials used in the manufacture of forms/moulds.

Timber - Very useful for short production runs. The surface must be properly sanded and sealed otherwise demoulding may be difficult.

FRP - Suitable for long production runs and good for shaped products. The gel-coat must be of an alkali-resistant resin. General purpose resins deteriorate rapidly when used with cement, causing a poor surface finish and very difficult demoulding.

Steel - Good for standard products and long production runs. Mould oil should be carefully applied to avoid any blemishes showing on the finished product. The weight of the mould can cause handling problems and sometimes can dampen vibrations on low-powered vibration tables.

Rubber - The most suitable types of rubber for this application are either polyurethane or silicone. These are two-component, cold-cure systems. They are pourable and readily conform to the patterning they are placed in contact with. The main advantages of using rubber moulds are their ability to reproduce very fine detail, they do not stress the product and demoulding is simply achieved by peeling the mould from the product.

13.11.4 Proportioning and Mixing

Mix design depends upon many parameters and a wide range of raw materials are used for premix GRC. Each product has its own particular requirements and records should be kept, enabling correlation of properties of cured product with the specified requirements. In premix architectural components, no less than 3% fibre content by total weight should be used. Lesser percentages may not provide adequate mechanical properties.

Most premix uses 3–4% fibre content with a chopped strand length of 12–24 mm. These mixes usually provide the best compromise between physical properties and workability – flowability.

Increasing fibre content over 4% reduces the workability of the mix. Further, most conventional mixes cannot incorporate fibre contents much higher than 4%. Longer fibres will have a tendency to reduce the workability and flowability of the mix and also create mixing problems due to an increased tendency to entangle.

The fibre should be added last, over a period not exceeding 2 minutes and the mixer should be allowed to run only for a sufficient time to fully incorporate the fibre, normally only a few seconds.

As with spray GRC, higher sand contents are desirable for reduced shrinkage, but sand contents higher than 1:1, may reduce flexural and tensile strengths of the composite to a low level. In addition, higher sand contents can reduce workability and flowability of the mix.

A typical premix formulation is:

Cement	46 kg
Sand	34 kg
Water	16 kg
Superplasticizer	0.5 kg
AR glassfibre (12 mm) chopped strand	3 kg.

As with sprayed GRC, it is desirable to use an acrylic polymer curing aid to eliminate the need for wet curing. The same polymer content as for sprayed GRC should be used.

13.11.5 Premix Procedures

Good premix manufacturing processes have the following characteristics:

- The mixing process should create a thoroughly mixed slurry, whilst producing minimal fibre damage, or entangling of the strands. This requires that the mixing process be capable of incorporating the fibres speedily and uniformly.

The best mixing processes are those similar to the Omni Mixer (generic description, not trade name), or the two-speed process in which the slurry is prepared in a high shear mixer followed by a slow blending phase in which the fibres are incorporated.

- Placing or casting of the premix must be done in such a way that the glassfibre strands do not orientate in any particular direction. Moving the premix over an excessive distance can cause this, particularly with long strand lengths (25 mm or more), **Figure 13.2**. Also, when casting, the moulds should be filled in a way that avoids two or more material charges. Knit lines can be created where flows meet and the fibres may not bridge the knit lines. This will create a weak point in the product which will inevitably result in cracking. Also, the mould must be filled in a manner that avoids pockets of air becoming trapped between the premix and the mould surface. Whenever possible, the mould should be filled from one point only (**Figure 13.3**). If the premix is pumped from the mixer to the mould, the mix must be designed such that separation of the mix components does not occur. A thixotropic aid in the mix such as methylcellulose or a pumping aid can prevent separation.
- Good premix properties require a water/cement ratio in the range 0.3–0.35. Workability and flowability must be achieved with the use of water reducers and super plasticisers.
- It is not usually possible to build up cast premix in layers, as is done in spray-up, rather the whole thickness is placed in one casting; rolling out is usually not effective with premix.

However, the mixing process inevitably incorporates some air into the mix and as the composite properties are density dependent, premix castings should involve vibration of the mix at some point, in order to expel as much as possible of this entrapped air. The vibration can be applied either during the transfer of the premix to the mould and or when the material is filling the mould. Excessive vibration must be avoided as this can cause separation of the mix components.

Any general release agent for use with precast concrete will work with premix GRC. In general, chemical release agents are preferred. It is considered preferable to:

- use as little release agent as possible, only a thin film is necessary;
- apply release agents by impregnated sponges or by spray.
- Note that excess release agent collecting in the bottom of the mould will cause discolouration and pin-holing.

Other points to note are:

- Removal of excess GRC whilst still wet is desirable.
- Final trowelling whilst still 'green' is recommended.
- Secondary vibration can have positive effects to settle the matrix.
- The filled moulds should be covered with 'plastic' film to prevent water loss during initial hydration.

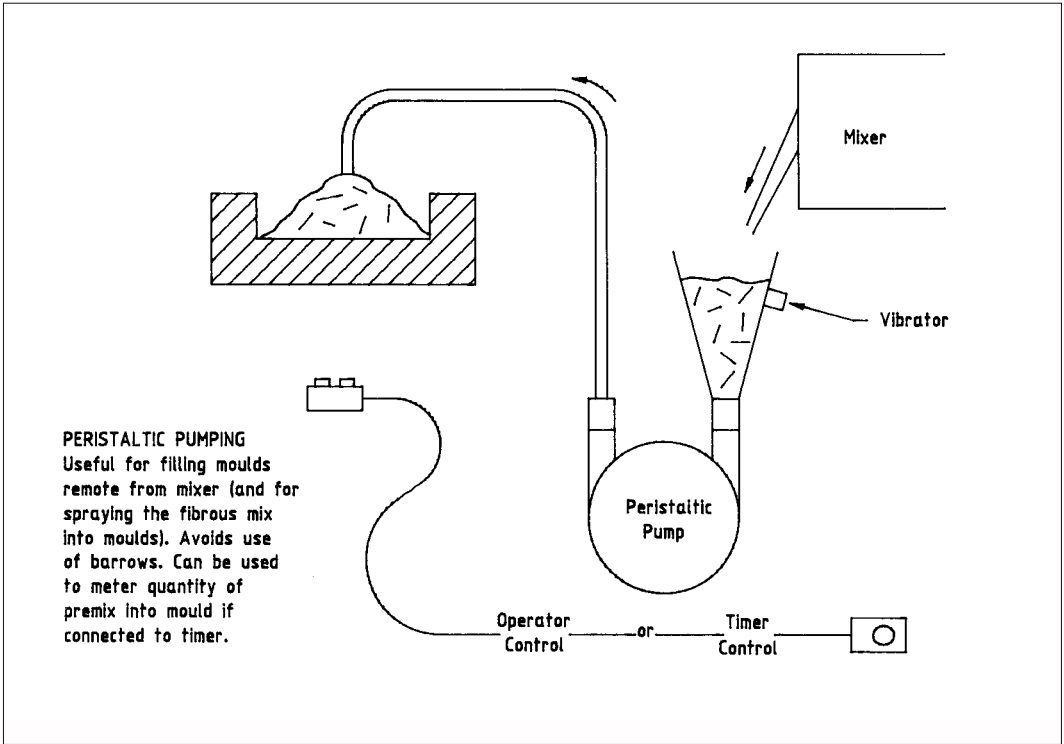


Figure 13.2 Suggested delivery method to the mould

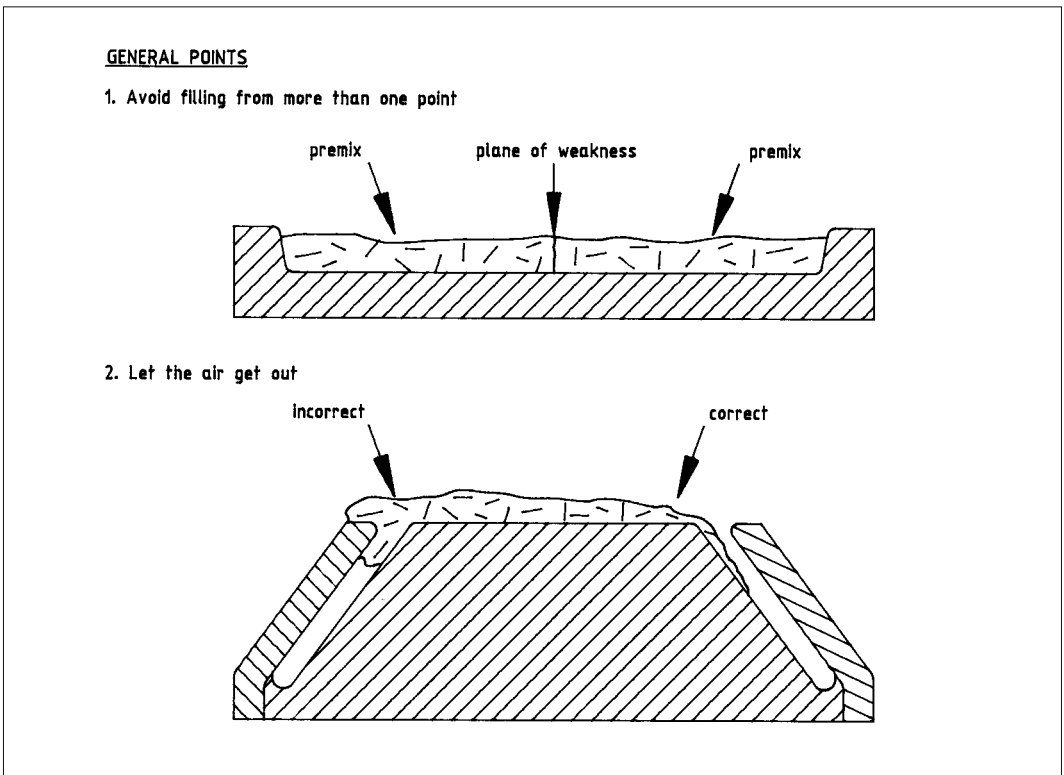


Figure 13.3 Placement suggestions

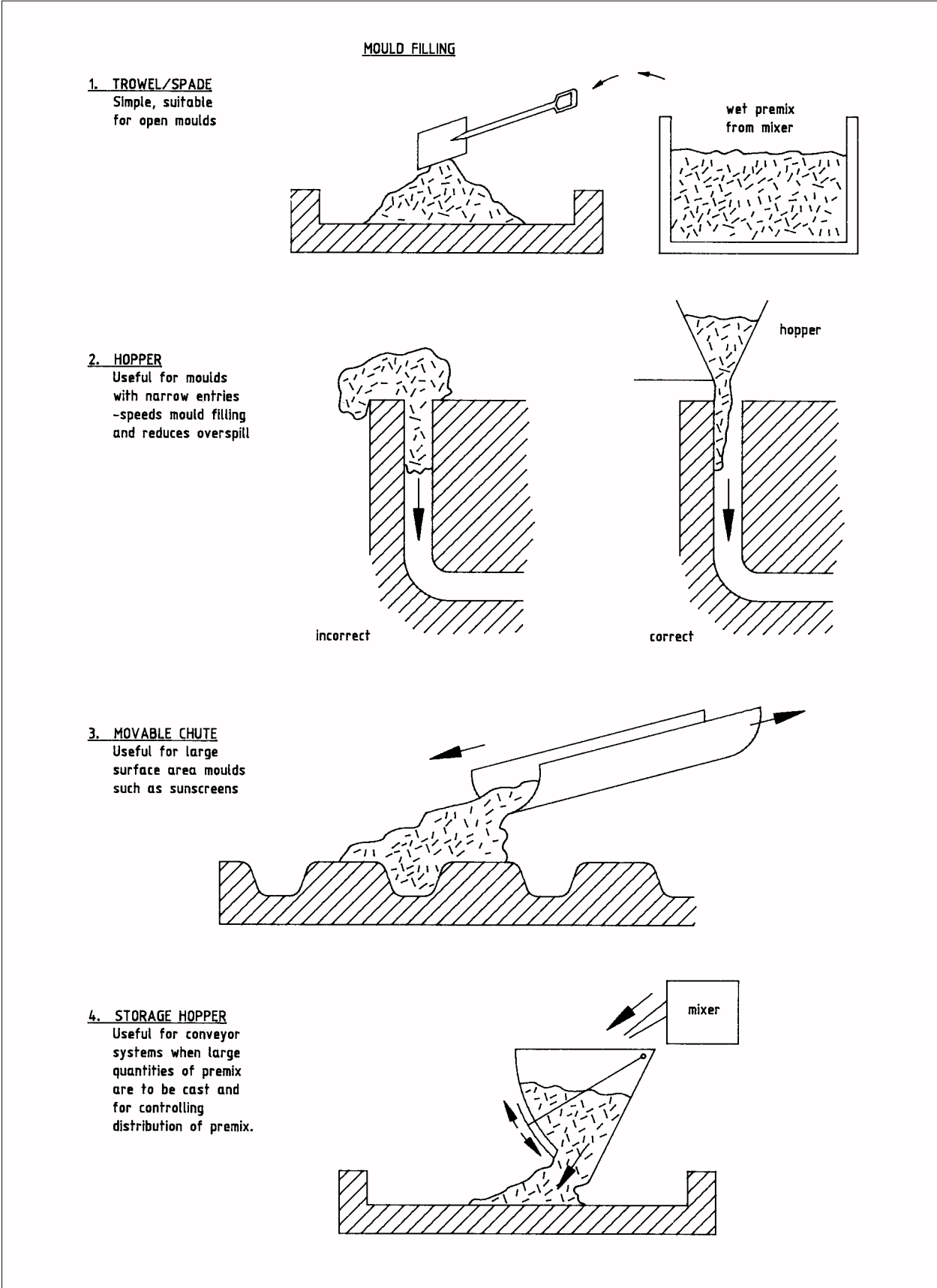


Figure 13.4 Further placement suggestions

13.11

13.11.6 Stripping

Some points on demoulding the product are worthy of note:

- It takes more time to demould, clean and re-apply release agents than it does to fill the mould.
- A steady force is more effective than hammering a mould, both from the quality of product and longevity of mould points of view.
- In the case of a double-skin mould, it is useful to extract the mould core as soon as possible after casting. This prevents the GRC from shrinking onto the core and making demoulding difficult.
- If a product is overstressed on demoulding it may crack at a later date. Demoulding should therefore be carried out with care.
- GRC products should NOT be allowed to dry out between demoulding and commencement of the formal curing regime.
- The mould should be cleaned as soon as possible after demoulding

13.11.7 Curing

Curing techniques and requirements are given in Chapter 6.

13.11.8 Quality Control

With the exception of those procedures designed to check spray-gun settings, such as bag and bucket tests, all quality control procedures recommended for spray-up are applicable to premix but it is worth noting the following:

- The glass content in premix is a finite measured amount so the checks required for panel sprayed GRC production are unnecessary in premix GRC, except to ensure the formulation weights.
- Thickness control is a function of the mould design and manufacture.
- Premix is highly dependent on density and this should be checked regularly, along with glass contents.

14 SPECIFICATION FOR MANUFACTURE, CURING AND TESTING OF GRC PRODUCTS¹

14.1
14.2

14.1 GENERAL

14.1.1 Specialist Contractor

The work specified in this section is to be undertaken by a Manufacturer who is a Member of the National Precast Concrete Association Australia, GRC Industry Group with experience in the GRC industry, which includes the production of architectural panels (or other products for which this specification is being used). With his tender, the contractor shall submit to the construction manager written evidence indicating his capability of producing panels of a reliable and consistent quality.

14.1.2 Standards and Codes

AS 3972:1997	<i>Portland and blended cements.</i>
BS 12	<i>Portland Cement.</i>
BS 3892	<i>Pulverised Fuel Ash for use in Concrete.</i>
BS 476	<i>Test Methods and Criteria for the Fire</i>
AS 3582.1:1998	<i>Supplementary cementitious materials for use with portland and blended cement - Fly ash.</i>
AS/NZS 1170.1:2002	<i>Structural design actions - Permanent, imposed and other actions.</i>
AS/NZS 1170.2:2002	<i>Structural design actions - Wind actions.</i>
AS 1170.4:1993	<i>Minimum design loads on structures - Earthquake loads.</i>
AS 1379:1997	<i>Specification and supply of concrete.</i>
AS 3610:1995	<i>Formwork for concrete.</i>
AS 1478.1:2000	<i>Chemical admixtures for concrete, mortar and grout - Admixtures for concrete .</i>
BS 1014	<i>Pigments for Portland Cements and Portland Cement Products</i>
BS EN 1169:1999	<i>Precast Concrete Products - General Rules for factory production control of glassfibre reinforced cement.</i>
BS EN 1170 Parts 1-8	<i>Precast Concrete Products - Test Methods for glass-fibre reinforced cement</i>

14.2 MATERIALS

14.2.1 General

Materials used for making the GRC unit shall generally comply with relevant British and Australian Standards and Codes. Any reference to a British Standard shall mean that current at the time of going to tender.

Where materials are not fully covered by this specification or alternative materials are offered, the Contractor shall forward to the Construction Manager prior to commencing the work, details of those he proposes to use together with supporting evidence indicating that the finished product will be capable of meeting the performance requirements of this specification.

14.2.2 Alkali-resistant Glassfibre

Glassfibre shall be an alkali-resistant, continuous filament fibre developed and formulated specifically to have high strength retention in Ordinary Portland Cement environments. The glass fibre shall have a minimum ZrO₂ content of 16% by weight, in accordance with internationally-recognised standards, and shall have a minimum strength retention (determined by Strand In Cement (SIC) testing) of 300 MPa (Test Method: GRCA SO 104/0184).

The producer shall provide certification from the glassfibre manufacturer to show that the glass fibre conforms to these requirements, has a history of successful use in similar matrices, and is manufactured under an internationally-recognised Quality Management system.

14.2.3 Cement

The cement shall be Ordinary Portland Cement, supplied by a manufacturer of assessed capability to AS 3972- 1997 and BS 12 or its derivatives, and should be supported by suitable certification. Cement shall be obtained from one source throughout manufacture.

Cement shall be correctly stored and kept dry to avoid deterioration.

14.2.4 Sand

Sands should be washed and dried to remove soluble matter, and to permit control of the water/cement ratio. Sand added to the mix shall not exceed 50% by weight of the total mix and sand/cement ratio shall not exceed 1:2. Sand shall be only high silica and conform to the following specification:

¹ This specification refers to the manufacture of Glassfibre Reinforced Concrete (GRC) products by the spray process. This process involves the simultaneous spraying of fibre and slurry onto a mould by manual or mechanical means. It is the commonly-used method of manufacture for relatively large GRC elements (eg cladding panels, noise barriers, permanent formwork) and other elements which are required to be thin in section and of high flexural strength.

14.2

Silica content	> 96%
Water content	< 2%
Soluble salts	< 1%
Grain size	< 1.2 mm < 10% passing a 150 micron sieve

Sands other than silica sands may be used subject to approval of the architect and engineer, but the producer must be able to show proof of their suitability.

14.2.5 Admixtures

The manufacturer shall ensure that any admixtures used do not have any harmful effects on the product, and are used in accordance with the manufacturers' recommendations. The use of superplasticisers may be encouraged to keep water content of the composite to a minimum without loss of suitable working characteristics, especially the ease of attaining full compaction.

Any admixtures used, shall comply with AS 1478.

14.2.6 Pigments

Any pigments used shall conform to BS 1014. These shall be:

- Harmless to the GRC's set and strength.
- Stable at high temperature.
- UV-resistant and alkali-resistant.

The client should recognise that some colour variation may occur, and must agree an acceptable range of variation with the producer.

12.2.7 Water

Water shall be free from deleterious matter that may interfere with the colour, setting, or strength of the concrete.

14.2.8 Mix Design

The mix shall have been determined by the manufacturer, and written confirmation of the mix design shall be submitted so the proportions shall be chosen to achieve the quality-control requirements specified herein.

14.2.9 Mould-release Agent

The mould-release agent shall be selected by the manufacturer and approved by the architect or engineer. This should be compatible with the surface finish required for the product. Any residue shall be removed from the finished product so that this does not interfere with any joint sealants or applied finishes which may be used.

14.2.10 Formwork

The design, material and manufacture of the forms shall be consistent with the type and quality of the surface finish required from the panel, and with the tolerances specified. The forms shall be constructed such that the finished products conform to the profiles and dimensions indicated by the contract documents.

14.2.11 Support Steelwork and Fixings

The Manufacturer will be responsible for the design, manufacture and installation of all support framing, cleats and fixings inserted into and affixed to the GRC panels, or provided for the support of the GRC panels. Fixing zones are described on the drawings, together with primary structural concrete and steelwork provided by others for use by the contractor if required.

Fixings shall be concealed and cast into panels unless otherwise specified. They shall be of non-corrosive material and located at suitable spacings to ensure support of panels without creating undue stresses to the panels under thermal movements and/or moisture movement.

The recommendations in Chapter 8 of this publication shall be incorporated in the design of fixings.

Steel materials and workmanship shall comply with the relevant codes, and all steel will be free from rust, loose scale, pitting and other defects.

Fabricated steel components shall be true to line and free from twists, bends and open joints.

All ungalvanised materials shall be thoroughly cleaned prior to fabrication, by grit blasting to Class 2 in accordance with AS 1627 Part 4 and painted with Red Oxide Zinc Chromate in two coats to a minimum dry film thickness of 80 microns.

Fixing cleats to existing steelwork, where indicated on the GRC cladding shop drawings, shall be site-welded unless otherwise arranged with the construction manager.

Any damage to protective coatings on steelwork, supplied as part of this contract works, shall be repaired.

14.3 WORKMANSHIP

14.3.1 Weighing and Batching

Dry ingredients shall be batched by weight using calibrated weighing equipment capable of an accuracy of $\pm 2\%$ of the stated batch weight. Liquids should be weighed, volume-batched or automatically dispensed. The producer must demonstrate that the method employed will give an accuracy of $\pm 2\%$.

14.3.2 Mixing

The cement slurry should be mixed in a high-speed shear mixer, or other high-speed mixer which can achieve a good and even dispersion of all slurry ingredients.

14.3.3 Application

Application shall be by spraying, using purpose-built equipment which allows the simultaneous deposition and uniform mixing of the glassfibre and cement matrix.

The glassfibre and cement slurry shall be metered to the spray head at rates to achieve the desired mix proportion and glass content. These shall be checked for each spray pump at least once per day and prior to commencing spray production after each stoppage. The test shall be conducted in accordance with the method described in BS EN 1170-3. Distribution of fibre in the mix shall be controlled by the operator in such a way as to be as uniform as possible.

Cleanliness of equipment and working areas shall be maintained at all times.

14.3.4 Shape and Finish

The panels are to be formed of GRC in moulds to achieve the profiles indicated by the architectural drawings.

The manufacturer shall provide a means for producing a replacement panel at any time during the building contract. Moulds shall be adequately cured to eliminate shrinkage and distortion and shall be properly braced.

The exposed face of the GRC panels surfaces shall be free of blowholes, cracks, undulation or similar imperfections.

14.3.5 Manufacture

The panels shall be manufactured by a spray technique as detailed in the NPCAA Recommended Practice or as otherwise agreed between the manufacturer and architect/engineer to an approved method.

Spray applicators shall be experienced personnel whose proficiency meets industry standards.

If an architectural face mix is being used, this will first be sprayed into the mould. The thickness shall generally be the minimum possible to achieve the desired finish, which will normally make it at least 20% thicker than the largest sand or aggregate being used and normally 4 mm minimum and 12 mm maximum thickness. An acrylic

polymer should be used in the face mix to reduce any risk of this unreinforced layer cracking.

If no face mix is being used, a mist coat consisting of the basic mortar composition without fibre may, if necessary, be sprayed onto the moulds to prevent fibres from being visible on the finished surface of the product. The mist coat is intended to be just thick enough to cover mould details and surfaces so that fibres are not visible on the surface, but not so thick that crazing of this unreinforced layer may occur.

The normal target thickness of a mist coat for non-polymer GRC is 1 mm, though the use of acrylic polymer in the mix may allow the thickness to be increased up to a maximum of 3 mm. However, it should be noted that for design purposes the thickness of the mist coat should not be considered as contributing to the strength of the GRC panel.

Spray-up of GRC backing material shall proceed before any mist coat or face mix has set.

The method of spraying the main body of material shall achieve the greatest possible uniformity of thickness and fibre distribution.

Consolidation shall be by rolling and such other techniques as are necessary to achieve complete encapsulation of fibres and full compaction.

Control of thickness shall be achieved by using a pin-gauge or other acceptable method. Minimum thickness of panels is recommended as 8 mm (hand-spray) and 6 mm (auto-spray).

All hand-forming of intricate details, incorporation of formers of infill materials and over-spraying shall be carried out before the material has achieved its initial set so as to ensure complete bonding.

Inserts shall be properly embedded into thickened, homogeneous areas of GRC. Waste material such as over-spray is not acceptable to encapsulate inserts or for bonding pads.

Any rigid embedded items bonded to the GRC shall not create undesirable restraint to volume changes.

14.3.6 Shop Drawings

Prior to commencing manufacturing work, the manufacturer shall submit for approval detailed shop drawings showing the following information:

- layout (sectional plan and elevation) of complete wall panelling;
- full-size section of typical panel and support members;
- method of assembly and supports and fixings to the existing structure and provision to withstand imposed stresses;
- method of installation, caulking, flashing and provision for vertical and horizontal expansion;
- junction and trim to adjoining surfaces; and
- fittings and accessories.

14.3

The submission of shop drawings shall be supported by engineering design computations to show that cladding and supports comply with the design criteria specified.

14.3.7 Tolerances

The GRC elements shall be manufactured and installed to the tolerances stated in Chapter 10 of this publication.

14.3.8 Demoulding and Curing

Once the initial set has taken place, GRC elements should be covered with polythene for their protection and to prevent them from drying out fully. They must not be moved again until they are ready for demoulding.

The GRC elements must not be demoulded until they have gained sufficient strength to be removed from the mould and transported within the factory, without being over-stressed.

If the GRC elements are too large to be demoulded by hand, special demoulding sockets or loops should be embedded in the panel during manufacture, and demoulding should be assisted with a lifting frame. This procedure should be agreed with the engineer.

During demoulding, the panels shall be uniformly supported in a manner which avoids undue stresses in the panels.

If polymers are used in the mix to avoid wet curing, the panels should be stored under cover for a minimum of 7 days at a temperature of between 5°C and 35°C.

If polymers are not used in the mix, curing shall be continued after demoulding under conditions which shall provide free water on the surfaces of the panels at a temperature not exceeding 50°C for a period of not less than 7 days (including the initial cure in the mould).

14.3.9 Identification of Elements

All panels shall be identified individually to indicate the panel type and date of manufacture.

At the time of preparation of shop drawings the manufacturer shall indicate his required order of delivery.

14.3.10 Handling, Transportation and Installation

The products shall be handled, transported and installed using methods which ensure that no damage or marking of architectural surfaces occurs and so that the panels are not subject to undue stress.

The safety and protection of GRC units shall be ensured throughout the whole of the contract works.

Site access and, if necessary, storage space shall be provided by the main contractor.

The main contractor shall also provide true, level and clean support surfaces and shall provide for the accurate placement and alignment of connection hardware on the structure.

14.3.11 Test Requirements

The specified glassfibre content shall be 5% by total wet weight of materials.

The GRC from which the panels are made shall have the following properties on completion of curing:

- Characteristic Modulus of Rupture (MOR) 18 MPa at 28 days.
- Characteristic Limit of Proportionality (LOP) 7 MPa at 28 days.

The value of MOR and LOP design stresses to be used should be determined by the design engineer for specific service requirements.

The minimum dry density shall exceed 1800 kg/m³.

14.3.12 Tests

The following tests shall be carried out on coupons cut from the test boards in accordance with BS EN 1170 Parts 2, 4, and 5. If acrylic polymer is used in the mix, presoaking immediately prior to testing shall not be required for Modulus of Rupture or Limit of Proportionality.

- i) Glass Content – BS EN 1170 Part 2
- ii) Modulus of Rupture – BS EN 1170 Part 5 (and simplified method in Part 4)
- iii) Limit of Proportionality. – BS EN 1170 Part 5

Test boards shall be produced alongside each day's production (at least one per day for each production team). The recommended size of these sample boards is 600 x 600 mm. The test boards shall be produced with the same quality, thickness and curing as the actual panels.

Those test boards which are not required for testing should be kept for the duration of the contract, or for a period to be agreed between the manufacturer and engineer.

14.3.13 Frequency Of Testing

The frequency of testing shall be agreed between the architect, engineer and manufacturer.

The recommendation of BS EN 1169 is as follows:

- Glass content – tested in accordance with BS EN 1170 Part 2. Once per week for each spray team. (This is in addition to the calibration test referred to in section 3.3).
- Modulus of Rupture and Limit of Proportionality – tested in accordance with BS EN 1170 Part 5. Should be tested by the manufacturer or by a qualified laboratory as the mix design is being set-up and thereafter at least twice per year, or when the mix design is changed.
- A simplified bending strength test to determine the Modulus of Rupture (MOR) should be conducted by the manufacturer more frequently. The frequency of testing recommended by BS EN 1169 is for each 10 tonnes of GRC produced, or at least once per week.

- Water Absorption and Dry Density – tested in accordance with BS EN 1170 Part 6. As the mix design is being set-up, and then for each 10 tonnes of GRC produced, or at least once per week.

14.3.14 Compliance

Compliance with glass content and the characteristic strength for both LOP and MOR shall be assumed if the following conditions are met:

i) **Glass Content**

The glass content shall not vary from the specific amount by more than $\pm 20\%$.

ii) **Modulus of Rupture and Limit of Proportionality**

The characteristic MOR and LOP is defined as the value which 95 per cent of all the mean strengths of the individual test-boards shall exceed.

Compliance with the characteristic MOR and LOP requirements shall be assumed if no single test-board mean shall be less than 85 per cent of the characteristic MOR and LOP, and the average of 4 consecutive test board results shall exceed 21 MPa (MOR), and 8 MPa (LOP).

If any single test-board fails to meet any of the compliance requirements, the GRC at risk shall be that produced between the previous complying test board and the next complying test board.

Where failure to comply arises from consideration of consecutive groups of four test-boards, the GRC at risk shall be that represented by the first and fourth test-boards, together with all intervening material.

Note: If different values for MOR and LOP are required for specific service requirements, these should be determined by the design engineer for the specific service requirements. The selection of unnecessarily high strength requirements may result in cost penalties.

iii) **Dry Density**

The dry density of the GRC shall exceed 1800 kg/m³.

iv) **Non-Compliance**

In the event of non-compliance, the action to be taken should be agreed between the manufacturer and the client. Due regard should be paid to the technical consequences of the non-compliance and the economic consequences of adopting remedial measures or replacing the rejected products. Account should also be taken of the safety factors incorporated in the design and also the thickness of the GRC produced, compared with the design thickness.

Re-testing may be considered appropriate if it is considered that the storage conditions of the product may result in improved properties because of extended curing, or if the sampling, testing or calculation may have been at fault.

The material at risk may be reduced by the testing of additional test boards from the same, previous, or next manufacturing periods. Testing may also be performed on GRC samples cut from the actual GRC elements at risk.

14.3.15 Weatherproofing

Responsibility for the weatherproofing of the whole installation of GRC panels rests with the GRC manufacturer.

The joint details shown on the drawings represent the appearance required and their minimum standard of weatherproofing acceptable.

Joints shall be weather-sealed with closed-cell polyethylene compressible backing rods and caulked with 2-part polysulphide sealant or other approved sealant in selected colours, installed completely in accordance with the sealant manufacturer's recommendations with regard to joint dimension, priming, substrates, mixing, curing, masking, cleaning and the like.

The GRC manufacturer shall submit details of the proposed sealant and the application recommendations for approval by the construction manager prior to commencement of the contract works.

Joints located and indicated on the drawings are those required for sealing the GRC cladding against adjacent materials and those required for architectural purposes for division of the panels into the design modules. Should the GRC manufacturer or contractor propose to subdivide the cladding into smaller panels for ease of casting, handling and erection, additional joints may be introduced in the design, provided the location proposed is discreet. The GRC manufacturer shall submit proposed locations and designs of additional panel joints with their tender submission.

14.4

14.4 OTHER ISSUES

14.4.1 Responsibility

The GRC manufacture shall be solely responsible for the design and performance of the GRC panels and their supports. Information provided on the drawings or this specification shall not affect this responsibility.

14.4.2 Guarantees

The Manufacturer shall warrant the GRC panels installed, or to be installed, against any and every defect or failure which may occur during the period of practical completion for the works arising out of any fault of the GRC cladding system, workmanship, fabrication, fixing or quality of materials used.

14.4.3 Design Criteria

Glassfibre-reinforced wall cladding shall comply with the following:

FINISH:

Class 2 as defined in AS 3610:1995 *Formwork for Concrete*, smooth face suitable for high paint finish.

DESIGN LOADS:

Cladding and framing shall be designed in accordance with AS1170.

DEFLECTIONS OF MAIN FRAME STEEL MEMBERS:

The attention of the contractor is drawn to the allowance made for differential deflections between the structure at level 2 and the ground. The anticipated allowance is 30 mm. The detailing of the GRC cladding should take this into account.