20 Australian Developments in GRC Design

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Background
Charles Rickard graduated from the University of Surrey, UK in 1975. There he was lectured by worldwide authority, Dr David Hannant in the subject of Fibreglass Composites which included Glass Reinforced Cement (GRC hereafter). After eight years of consultancy and contracting experience in the UK, he migrated to Sydney, Australia in 1984. In establishing his company Rickard and Partners, he soon found his training and experience in composites was of value in not only GRC but also Fibre Reinforced Plastic. In 1999, he was contracted by the GRC Industry Group of the National Precast Concrete Association Australia to produce the document 'Design Manufacture and Installation of GRC'. In the last 27 years, he has worked in the GRC industry in the USA, Singapore, Hong Kong, UK, the Middle East and Australia. In 2005, he retired from his successful, established firm to allow him to spend more time working on his own as a specialist engineer.

Tony Grosset of Grosset Consulting and Construction originally founded Glenn Industries in 1962, based in Adelaide, South Australia. This company specialised in modular construction. In 1975 they were one of the first to pioneer the manufacture of Glass Reinforced Cement (GRC) in Australia, obtaining one of Pilkington UK licences. In 1975 he became the inaugural president of the new GRCA of Australia. Over the next 30 years, making use of his broad engineering background, he developed many new factory built modular building systems. The company also made large investment in research and development for the application of a large range of surface coatings to suit GRC. One other development was in the free form spraying of GRC. Ultimately this led to developing the 'Dots in Space' spatial surveying programme (DIS), used to produce large free form structures from a maquette model. In 2006, he retired as the managing director of Glenn Industries to concentrate on promoting GRC to clients, architects and designers through proven experience.

In the last 27 years, Tony Grosset and Charles Rickard have collaborated on many projects, some of which are described in this paper.

Introduction
In 2010, Charles Rickard became involved with Tony Grosset of Grosset Consulting and Construction to design and build the largest panels ever attempted in Australia, being 9m long x 3.2m deep with a 1500mm wide return. A world wide literature search revealed that such panels had never been attempted before due to concerns on the stresses that would be developed in the panel due to the restraint provided by the return at one end. This paper sets out how they overcame the issues and the results attained at prototype stage. The prototype of these were developed and built by Glenn Industries in Adelaide, South Australia. The panels are now in full manufacture with Precast Industries of Brisbane, Australia. Finally, in the subsequent sections of the paper, we highlight the work that we have both done together in free form GRC structures and our development of what we understand to be the world's first prestressed GRC element.

Large Steel Framed GRC Panels Incorporating Large Returns
In the course of his career, Charles Rickard spent time working with GFRC Texas, just outside of Dallas, USA. They produced a whole range of large panels, some as big as 8m tall and 4.5m wide. Often they

would introduce a full expansion joint within the face of the GRC to limit stress generation due to shrinkage. Sometimes they would incorporate a bonded stone facing on the outside of the GRC, with painted GRC elsewhere on the same panel. There would be separation between the two finishes, again to limit shrinkage stress.

In 2010 the Grosset/Rickard team were contracted to design and supply large panels for the expansion of the Museum of Contemporary Art, Sydney Australia. The museum is located on Sydney Harbour at Circular Quay. It is the old Customs House and is a sandstone clad building of classical art deco detailing. The decision to enlarge the museum presented an architectural challenge which was answered by a design which is totally different from the original building [Figure 1]. A key part of that design is the creation of a series of boxes of differing colours. The architect insisted that the boxes were not jointed on the corners, but seen to be monolithic. As a result, the panels incorporated large returns 1500mm wide, sometimes on panels 9m long x 4m deep.

A world wide inquiry into current practice with regard to the incorporation of a large return upon a large panel confirmed that such an idea was contrary to good building practice and should be discouraged. At the same time, transportation limitations into Sydney meant that the original proposed depth panel of panel of 4000mm was reduced to a panel only 3200mm deep. The returns were retained. Grosset and Rickard had no alternative but to proceed to build the panels as requested by the architect. A further complication with the panels was the insistence by the architect that the panels were to incorporate 6 different integral colours, ranging from pure white to pure jet black.

The challenges involved in this project were principally fourfold;

1. The spraying of a 1500mm high 90 degree x 3200mm deep return on a panel already 9000mm long x 3200mm deep.
   A prototype panel was built in Adelaide by Glenn Industries in January 2011. After a number of trials, they decided to utilise a 'folding mould' to create the 1500mm high return. The concerns of Glenn Industries were that trying to spray a vertical surface of GRC would lead to slumping and weakness in the matrix. By the end of producing three different prototypes, Glenn Industries had perfected the system to the point where they were happy to recommend the method for full manufacture.

   In April 2011, manufacturing was moved to Precast Concrete Pty Ltd in Brisbane. Their prototype design, building upon the experience gained in Adelaide, enabled them to avoid the use of a 'folding mould' by careful water cement ratio control and workmanship, involving progressive build up of the skin. Logical concerns on laminar bond meant strict control to avoid cold joints.

2. The design of the steel frame of sufficient rigidity to hold the panels square during the processes of de-moulding, transportation and erection.
   Experience learnt by Charles Rickard in the USA is to generally use a hot rolled steel frame around the perimeter of the panels with smaller infill members to pick up the flex anchors to the GRC. In the States, they often use cold form sections as the internal members. In Australia, the preference is to use hot rolled box sections of a smaller size. Wind loading on the building was relatively low at +/- 1KN/m^2 so this was not a major design issue. Engineering judgement was required to assess the rigidity needed to hold the panels square while under duress of the stresses caused by shrinkage and also transportation. A 100 x 100 x 4mm thick box section was adopted and this has proved to be a success. Internal members were 50 x 75 x 3mm thick [Figure 2].

3. Design of the connection between the steel frame and the GRC as to relieve shrinkage stresses generated due to the restraint created by the return on the steel frame.
   The concept adopted here is illustrated [Figure 2]. Gravity anchors were installed at the mid depth point of the panel. The Adelaide prototype utilised inclined flex anchors beneath the standard flex anchor. The Brisbane construction panels utilised cast in rigid plates. Both have been equally successful. The reason for positioning the gravity anchors in the mid height of the panel is to minimise the restrained shrinkage to half of the panel height rather than the full panel height if those gravity anchors were positioned at the base of the panel. Whilst certain manufacturers do not wish to have any part of the skin in permanent tension, in reality, the ability of the flex anchors to cantilever and carry the self weight of the GRC individually is such that the already low theoretical stress is in practice zero anyway.

   The Adelaide prototype incorporated plastic sleeves on the stems of the flex anchors to help eliminate restraint on the longitudinal shrinkage. The disadvantage of the plastic sleeves is that it reduces inherent rigidity to withstand the stresses and strains of transportation. The Brisbane panels did not incorporate the plastic sleeves hence improving transportation rigidity. Much to the engineers delight, the strength of the GRC in shrinkage was sufficient to debond from the flex anchors. The measured shrinkage on both panels after 7 days proved to be identical at around 10mm on the 9m length. We refer to [Figure 4] which is an extract on the calculations used to assess predicted movement in the panels. Based on a maximum shrinkage of 1.5mm per metre, it was assumed that 50% would be lost in the manufacturing process. In practice, 66% was lost in the manufacturing process [Figure 3]. 10mm shrinkage was measured within 3 days.

   The key design element was the way in which we allowed the shrinkage longitudinally to be limited to half the panel length, rather than working from the 1500mm return on the one end. Grosset and Rickard developed a sliding flex anchor. A hollow steel tube is welded to the steel frame into which a threaded steel flex anchor bar is inserted with locking nuts. As the GRC shrinks along the 9m length, so the 1500mm unrestrained return is drawn inwards. The general experience with such returns is that the outer edge of the return kicks outwards as the integral end is drawn inwards. The sliding connector allows adjustment of the return to maintain a right angle. It is important to ensure that the GRC is kept away from the stem of the flex anchors so that the skin does not bind. The detail is simple and easy to implement and has proved to give the manufacturer more than sufficient adjustment [Figure 4].

   The proof has been that monitoring of the skin upon the flex anchors along the 9m length has shown that equal movement is occurring at either end of said 9m. The lock nuts will be locked either side of the hollow tube, prior to transportation. Rickard has nominated that the age of the panels must reach at least 14 days prior to transportation due to their length and the extremity caused by the large return.

   Panel fixings to the building are 6 per 9m length (3 top and 3 bottom). In addition, the option is there to have panel to panel connections to overcome manufacturing tolerances for the long 1500mm cantilever.

4. GRC mix design to overcome the impact of efflorescence upon the 6 different colours involved in the contract.
   The architect's insistence on integral dark colours has proved a great challenge on the manufacturing control. The Rickard and Grosset experience on an earlier project for a railway station in Chatswood, Sydney with large black 2D panels was that the efflorescence within the

panels was still noticeable on dark colours 3 years later. Much of this had to do with inappropriate storage by the main contractor after the delivery of the panels. However, it highlights the concern on this particular building where the architect was looking for sharp contrasts between 6 different colours. The dark Chatswood Railways panels have had this problem accentuated by the application of anti-graffiti coatings.

Different manufacturers have different mixes, each of which will have its own characteristics with regard to efflorescence. Prototype testing and subsequent monitoring of the dark brown panel in Adelaide for efflorescence has shown that the addition of Silica Flume as a replacement for part of the cement in the GRC matrix to reduce 'free limes' has reduced efflorescence. The application of a polisyloxane coating system after curing has improved waterproof qualities and provided a surface that is easily cleaned. Efflorescence is not usually of a concern on white or light pastel colours. A lesson to learn for the industry, in Australia at least, is to develop much better definitions of surface tolerance and acceptable contractual integral colour variance.

Prestressed GRC Elements

All of the design focus with GRC is generally to do with shrinkage and its tensile capability. Very rarely does anyone ever focus on the compressive advantages of the material. We refer to the original Pilkington Design Guide first produced in 1977, which nominated a compressive strength between 50-80N/mm^2. We remind everyone that this is similar to the highest grade of concrete.

There are three general forms of panel manufacture which have developed over the last 50 years.

1. GRC supported on a steel frame.
2. GRC utilising polystyrene or polystyrene bead concrete cores.
3. GRC with integral ribs.

In 1992, Glenn Industries became involved with the production for the GRC elements in the new Australian Tax Office in Adelaide, South Australia. One of the elements was a sun hood, spanning 4.5m, approximately 1200mm wide, capable of withstanding a 1.5KN point maintenance load for window cleaners. The top surface of the panel was perforated. The architect did not wish to see any exposed steel work. Together with their design engineer, Charles Rickard, they developed a panel which utilised the compressive strength of GRC to allow the use of the concept of prestressing to span 4.5m without use of any steelwork except a tensioning rod located at the base of each side rib. The panels were post tensioned at 28 days to allow elimination of as much shrinkage as was possible. The rods were designed to slip in a retainment sleeve. The rods protruded deliberately and provided an elegant and easy way of mounting the panels to the vertical GRC styropor fins fixed to the building [Figure 5]. The top of the panels were screeded and finished with a smooth steel trowel finish ready for surface coating.

The integrally cast penetrations in the top of the sunhood panel provided significant solar heat reduction by shading the windows. The sunhoods varied in thickness allowing the angle of incidence of the sunrays though the penetrations to be engineered and varied. This provided the required shading to the large glass windows, and reduced the heat transfer into the building which significantly reduced air conditioning operating costs.

The sun hoods and the parapet panels were factory finished with PVf3 coating system, which provided an extremely durable, dirt release finish with minimal long-term maintenance requirements. Properly maintained PVf3 coating system has an expected life in excess of thirty years with accelerated exposure tests indicating 80% colour and gloss retention over this period.

The building is now 15 years old [Figure 6]. The sunhoods were recently inspected as part of routine maintenance. Relaxation due to ongoing shrinkage in the panel was allowed in the prestressing calculation. We are pleased to note that there has been no need to tighten the tensioning rods to date. In view of the age of the building, none is now anticipated. Clearly GRC provides a clean, elegant solution which would otherwise involve complications of obscuring structural steel sections.

Free Form GRC Structures

In 1985, soon after his arrival from the UK, Charles Rickard was contacted by Ross Cooper of ACI Fibreglass Australia, enquiring whether he could assist the Mokany brothers to build a 13m Big Ram, in the town of Goulburn, on the highway, halfway between Sydney and Melbourne. The shape and nature of the product was clearly such that the use of form work and off site manufacture would be uneconomical. Therefore, Charles Rickard decided to use a system of free form spraying on site, involving a structural coat and an architectural coat onto a lightweight steel mesh, now known as the armature. A key part of the design was to provide a structural steel frame compatible with the eventual shape of the GRC, providing sculpture flexibility by means of traditional flex anchors which could be trimmed to length by the sculpturer. Tender documents were duly prepared and the GRC tender was won by Glenn Industries of Adelaide. Unknown to Charles Rickard, Glenn Industries had previously designed and built the Magic Mountain in Glenelg in Adelaide.

The Big Ram was completed in 1985 [Figure 7]. The Mokany brothers, buoyed by the commercial success of the Ram in Goulburn, proceeded to build the Big Prawn in Ballina (1987), near the NSW/QLD border [Figure 8] and the Big Oyster in Taree (1988), which is a country town 4 hours north of Sydney [Figure 9]. The same engineering and GRC manufacturing team were used for all three projects. In 1993, Glenn Industries foray into Asia had resulted in establishing connections with Caravelle Constructions in Singapore to build a 37m high Merlion on Sentosa Island. The Merlion is Singapore's national emblem, consisting of a lion's head on the body of a fish. Glenn Industries produced a prototype maquette of the statute which was the subject of an extended period of adjustment and fine tuning by the Singapore Government reporting to Lee Kuan Yew himself. With the first generation of the 'Dots in Space' programme, they built the intricate armature incorporating 3600 Special fibre optic light tubes, integrally cast into the GRC skin for their nightly musical light show. The GRC engineered skin was sprayed on the armature to faithfully reproduce the shape and form of the Merlion. Glenn's artisans reproduced the maquette's intricate detail approved by the client. The GRC was integrally coloured with oxide and the surface was stained to provide realism.

Caravelle Constructions constructed all of the piling, reinforced concrete and structural steel to a design prepared by Rickard and Partners in Sydney. The structure contains 2 lifts to an observation deck set in the head of the Merlion. Glenn Industries subsequently visited site with their sculpturer to build the intricate armature and GRC to create the finished structure. Today, 18 years later, the building is structurally sound and there have been no maintenance costs associated with the GRC skin [Figure 10].

In 1998, as a direct consequence of the work done in Singapore, Glenn Industries and their engineer Charles Rickard were invited to design and build the Body Zone for the New Millennium Experience Company in London, as part of the Bi-centennial celebrations held in London, under the Millennium Dome. Working closely with UK engineers Bureau Happold who were responsible for the steel substructure, the amazing creation of a male embracing a female was 96m long x 38m high. It was completed ready for the celebrations in December 1999 [Figure 11].

One of the most interesting aspects of the creation of these free form structures over a 13 year period was the development of the support technology. For the three structures in 1984 to 1987, drawings were created to the approximate shape of the eventual structure and the onus was on the sculpturer and Glyn Sennar of Glenn industries to create the finished product. For the 'Big Ram', the client Atilla Mokany visited a merino stud farm near Goulburn and photographed a particular animal to be the contract reference for his project. For the 'Big Prawn' and the 'Big Oyster', the Rickard and Partners design team visited the local Fish Markets in Sydney and modelled their drawings on particular specimens enlarged with the help of a photocopier. By 1993, when designing the Merlion, the team had progressed to building a 1m high markette (miniature statue) which enabled coordination of structural steel and GRC to a much higher degree of accuracy. By 1998, Glenn Industries has developed their 'Dots in Space' (DIS) computer modelling system which allowed the maquette to be generated in 3D form. Subsequent construction on site was to an accuracy of 5mm.

The design of these structures needs to recognise the brittleness of the GRC in relation to the rigidity of the support frame. The design of these structures needs to recognise the GRC matrix design required for open air curing and the application of the finishing coatings. There is no question that the use of this type of technology provides a valuable option in the building industry. There is no limit to the shape and size of structure which can be considered, particularly when one considers formwork costs associated with producing panels with no repetition in mould use. None of these structures have ever needed a waterproof layer. However each project must be considered on case by case basis.

Conclusion

The predominance of 'design and construct' contracts in Australia has had a severe impact on imaginative façade solutions beyond concrete, steel, aluminium and glass. The downturn in the building industry in the Middle East has seen many architects and engineers returning to Australia having been exposed to the frequent use of GRC in that part of the world. This has resurrected the industry in Australia and there are now a significant number of large GRC projects either in construction or in planning. We hope that you find these ideas on; large GRC panels with large returns; prestressed GRC elements; free form GRC structures to be of value to you in your business.

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FIGURE 1: Architectural Perspective of Museum of Contemporary Art's GRC Façade. Architect Marshall and Government Architect's Office in association. Image by Luminova.

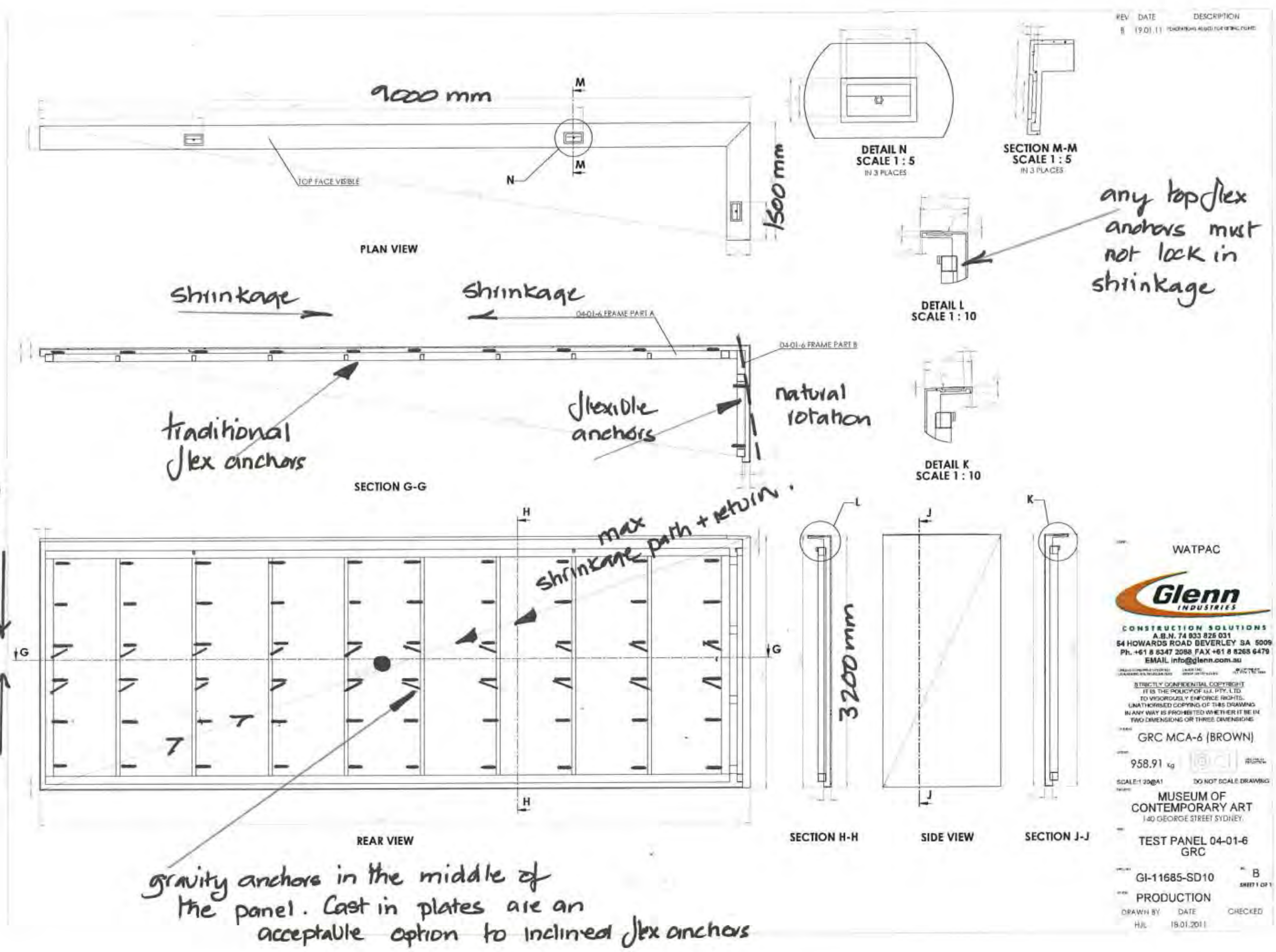


FIGURE 2: Prototype Design of 9x3.2m Steel Frame GRC Panel with 1500mm Return

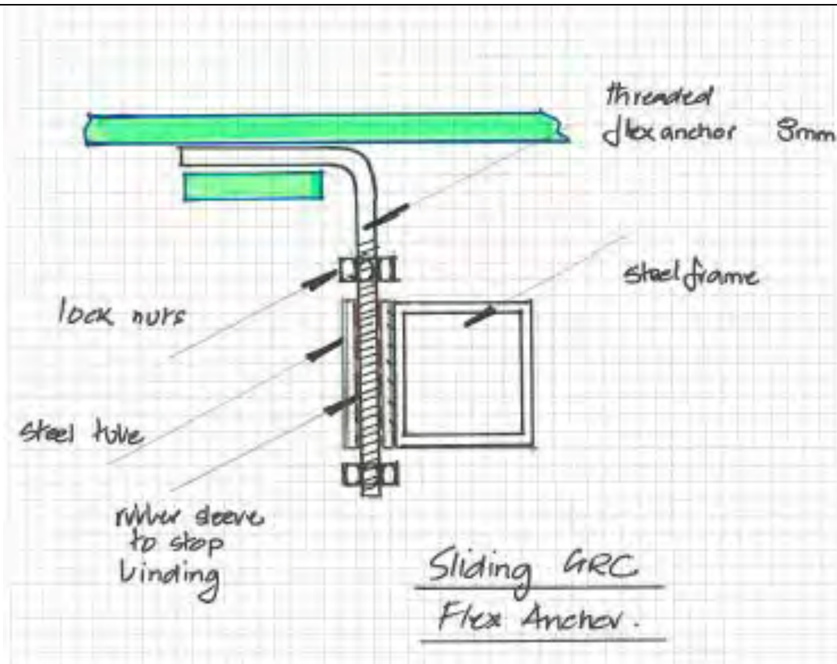


FIGURE 3: Engineering Analysis of Likely Panel Movements Validated by Prototype Results

• Neville Concrete

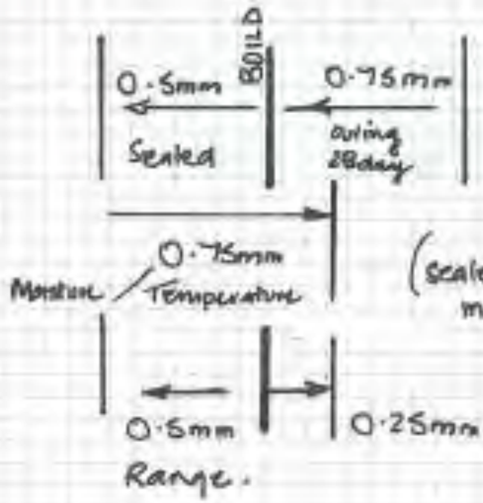
Ref: • NPCAA "GRC Manual"

Panel Joints.

• Fridger Warehouse . "GRC in Buildings"

• Pilkington Manual

• Max shrinkage = 1.5mm/m.
• Accepted shrinkage post curing 0.5mm - 0.75mm/m
• Panels sealed
• Reversible movement temperature = 0.75mm/m.
  — accepted value



Neville:
• max reversible shrinkage 70% resisted by sealant

(sealed minimise moisture.

(• max temperature cannot be max moisture in panel.)

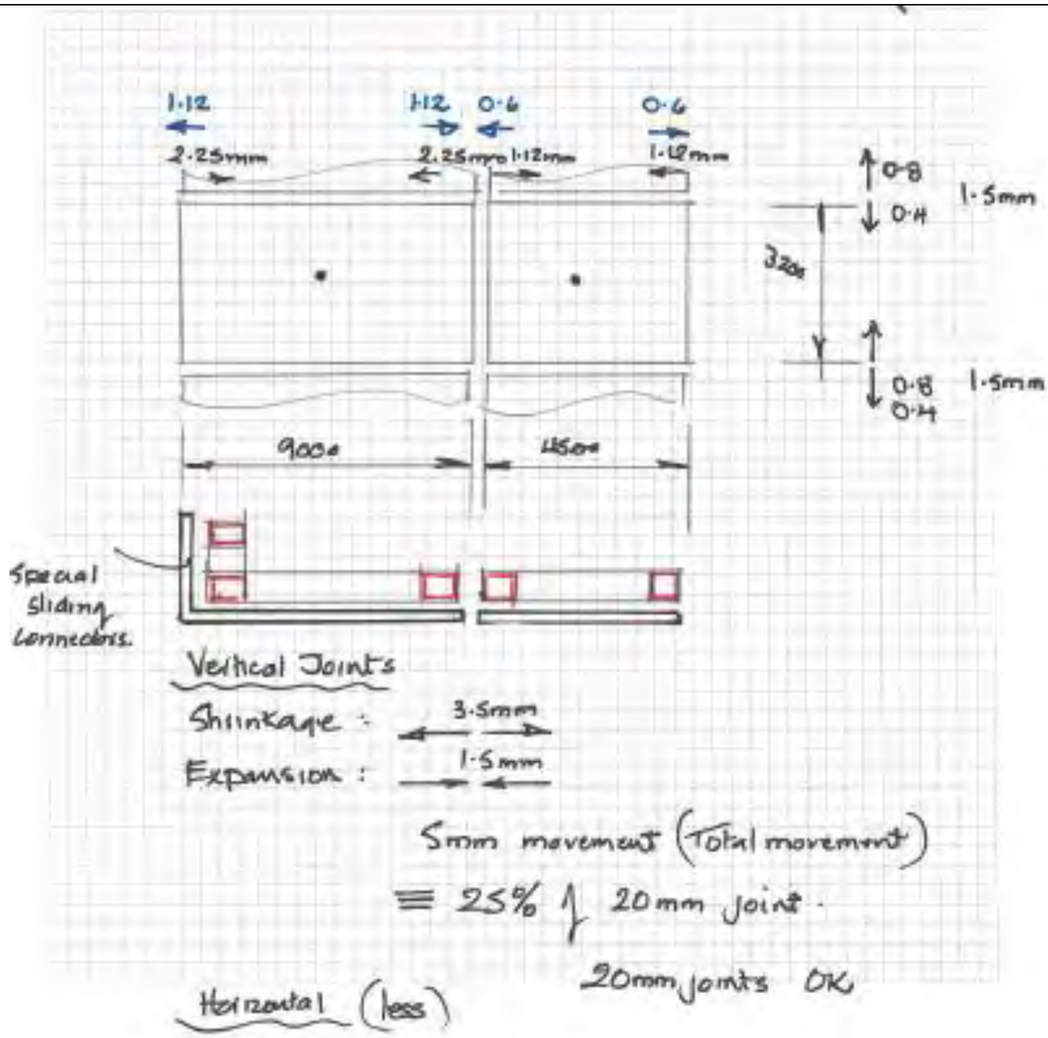


FIGURE 4: Design of Sliding GRC Flex Anchor to Relieve Locked in Stresses on 1500mm Return


FIGURE 5: Adelaide Australian Tax Office Prestressed GRC Sunhood Panels

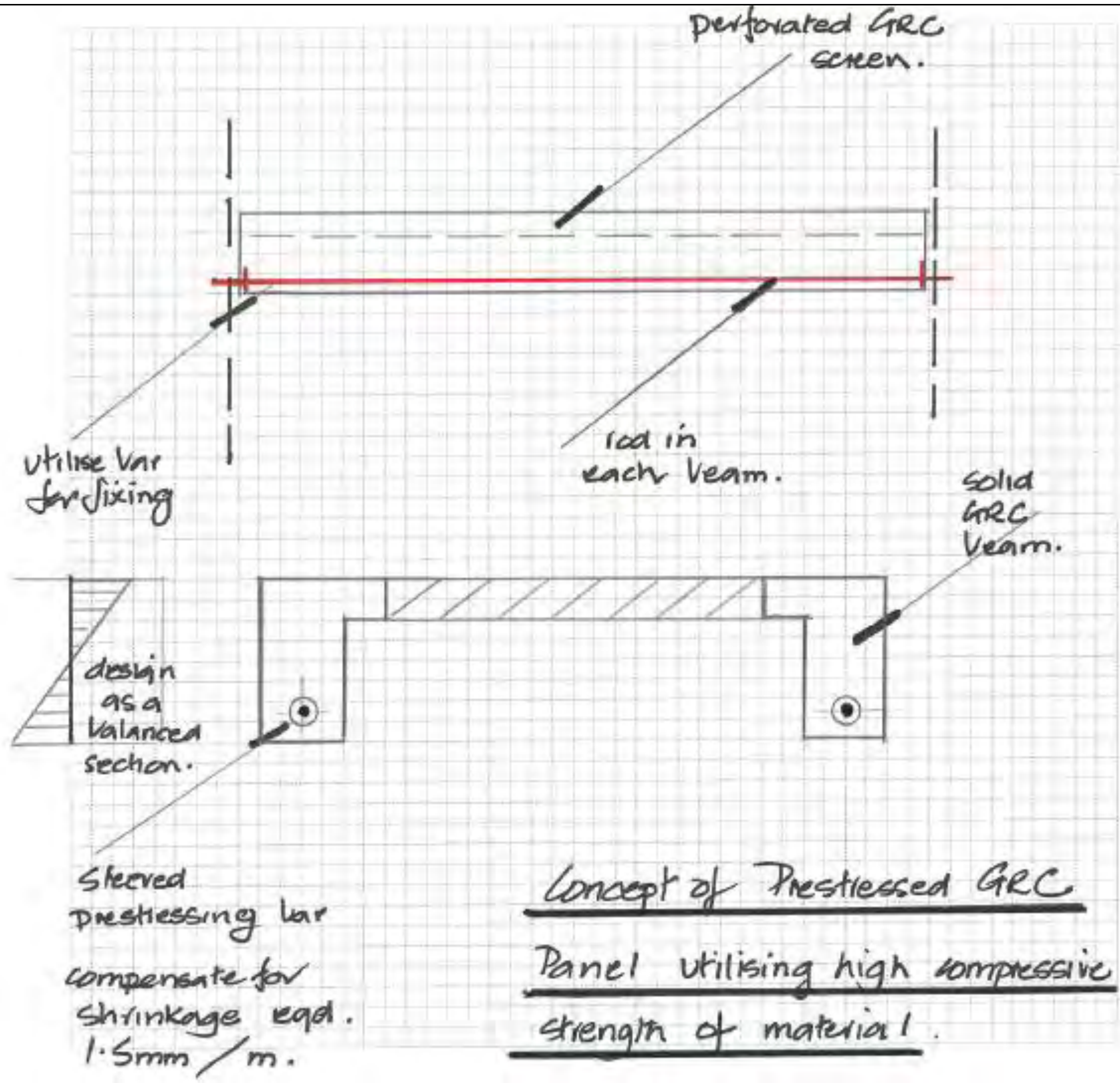


FIGURE 6: Engineering Concept Details of Prestressed GRC Panel

FIGURE 7: The Big Ram Goulburn NSW; GRC Free Form Structure

FIGURE 8: The Big Prawn Ballina NSW; GRC Free Form Structure

FIGURE 9: The Big Oyster Taree NSW; GRC Free Form Structure

FIGURE 10: 37m High Singapore's National Icon; The Merlion, Sentosa Island; GRC Free Form Structure

FIGURE 11: The Body Zone, Millenium Dome, London; GRC Free Form Structure