10 THE PRACTICAL DESIGN OF GRC IN HONG KONG

D. SENECAUT
Redland Precast Concrete Products, Hong Kong

SUMMARY: The paper presents the practicalities of GRC design, mainly for cladding, in a place distant from the developed markets of Europe, North America and the Middle East.

The use of GRC in Hong Kong was initiated by Redland Precast in 1994 under the wing of a pair of knowledgeable British consultants, but very few people had even heard about this material. The building authorities, responsible for every aspect of every project before the 2002 reform, were the first to be convinced. However, most of the consultants and architects were dubious and it took a lot of testing before they could start and feel more confident to specify GRC.

This led Redland Precast to carry out its own tests because either they had not been done by any other GRC manufacturer, or they were not done on the same GRC formulation. The critical aspects of GRC architectural design and performance that have been investigated can be grouped under four headings:

- Durability
- Joint design
- Mix design
- Fixing design

The save-all solution of building a mock-up is also discussed in this paper.
KEYWORDS: Cladding, durability, fixing design, joint design, mix design, mock-up, practical design, testing.

INTRODUCTION

While Redland Precast have designed and produced various types of GRC elements, for example parapets, permanent formwork, cable troughs, cladding and architectural mouldings, I will concentrate on aspects related to **architectural finish cladding panels**, whether they are ribbed panels, stud-frame panels or sandwich panels.

For us, the function of design is a service to the construction industry and the community in general by providing the base for responsible fabrication and installation of quality elements. Long before the sustainability buzz, designers had indeed focused on making things beautiful, safe and economic. In the academic world this is usually thought of as 'design a product to its functions' and the functions of a GRC architectural finish cladding made us consider the design required in relation to four areas:

- architectural design
- load-bearing capacity
- sound and thermal insulation
- fire resistance.

Since most of the cladding we design is non-load bearing and does not form the building wall, we can group the performance required into two groups based on their relevance:

Non-critical	Critical
Sound properties	Appearance (weathering)
Water absorption	Weight
Water vapour permeability	Fixings strength
Air permeability	Thermal- and moisture-induced movement
Fire resistance	Water tightness of envelope

For this presentation, I will focus on the four main aspects that we have investigated to satisfy queries raised by the consultants, Building Department, clients, production, installers and quality control (QC) inspectors:

- durability
- joint design
- mix design
- fixing design.

DURABILITY

Strength retention
This design query is not specific to Hong Kong but is raised systematically because of a lack of understanding and a tendency among local engineers to need numbers, formulas and standards.

The emphasis on experience and past projects as outlined, for example, by Mr Liozu in the last GRCA(1) Congress (Barcelona, October 2003) may be enough for preliminary discussions with developers and architects but is of no help to the design team.

Part of this reticence is, however, valid due to local weather specifics: 25 years' UK weather is not the same as Hong Kong weather. High winds, the marine environment, and the combination of hot and humid weather are a big factor of the local design practice.

To address practically these concerns, we have run our own accelerated ageing tests and carried out full-scale load tests.

Accelerated ageing tests

1. The first graph (Figure 1) represents the evolution of the ultimate and yield flexural stress as a function of the number of days in 50°C water.

   We note a sharp decline in ultimate flexural stress up to about 50 days after which the results stabilize. This is the 'long-term stable value' which is around 12.5MPa.

   The yield stress declines very marginally from 11.7MPa to around 9MPa.

2 The second graph (Figure 2) represents the same properties for the samples, this time immersed in 80°C water.

   Similarly while the modulus of rupture (MOR) decreases up to 7 days, it then stabilizes to around 14MPa. The limit of proportionality (LOP) here increases slightly from 9.3MPa to 11MPa.

3. The third graph (Figure 3) represents the average stress–strain curves for the samples in 80°C water.

   These curves have been made by averaging the curves obtained for each coupon tested and then relating them to an identical section to compare stresses rather than strengths.

   Although the 10-day and 7-day curves seem interchanged, we again note the general reduction in the ultimate stress and more visibly in the ultimate strain.

4 The fourth graph (Figure 4) shows this reduction in the ultimate strain from 0.5% to about 0.14%.

   As a conclusion of the above, we have seen that the fully-aged GRC simulated by immersion in hot water has the following properties:

   - a stable MOR value of around 13MPa
   - a stable LOP value of around 10Mpa.

These values confirm the assumption that aged MOR is superior to unaged LOP and the tests carried out thus fully reproduce similar tests carried out in the UK, the USA and Japan and confirmed our design assumptions.

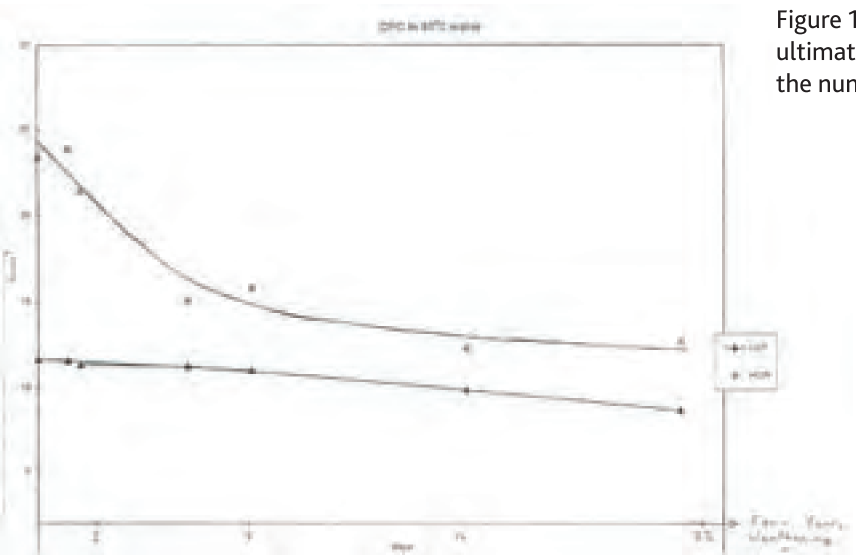

Figure 1 - Graph representing the evolution of the ultimate and yield flexural stress as a function of the number of days in 50°C water

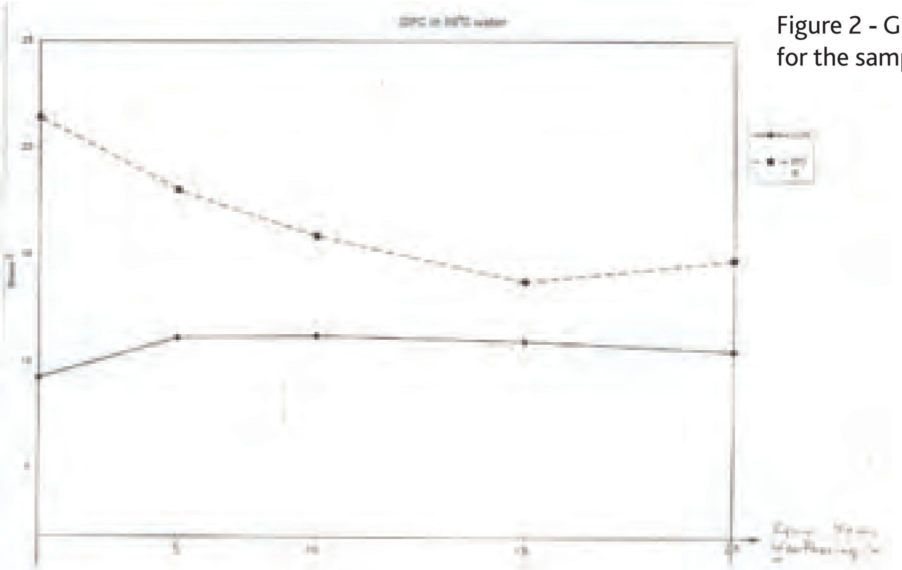

Figure 2 - Graph representing the same properties for the samples, this time immersed in 80°C water

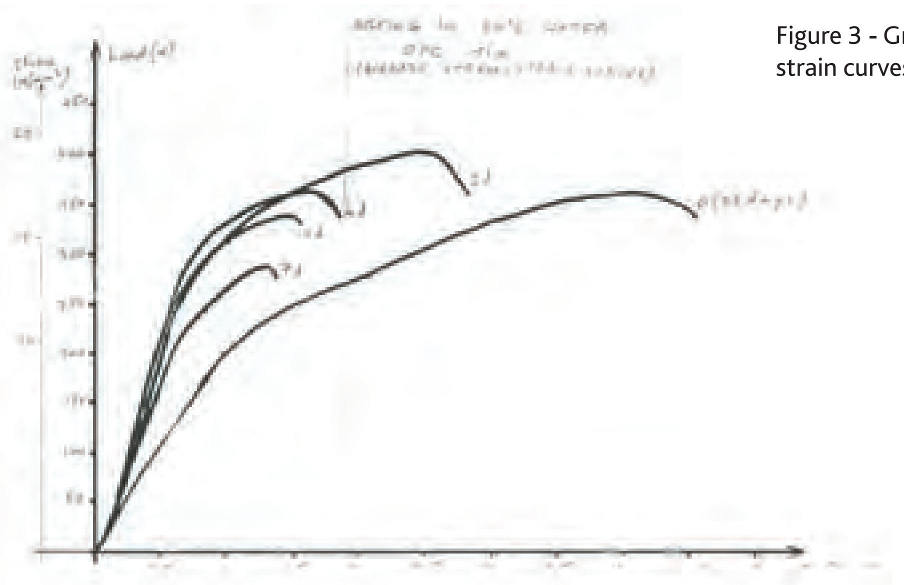

Figure 3 - Graph representing the average stress–strain curves for the samples in 80°C water

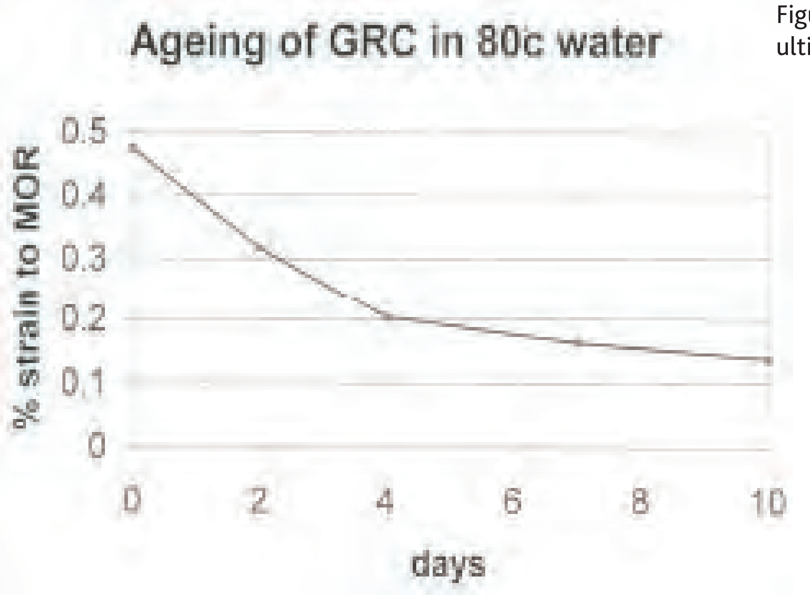

Figure 4 - Graph shows this reduction in the ultimate strain from 0.5% to about 0.14%

Full-scale load tests
The Hong Kong Buildings Department previously approved our design calculation conditionally: 'Under Section17(1)(6) of the Buildings Ordinance, safety test on representative sections of the proposed glass reinforced cement cladding including the fixings and fastening is required to be carried out to verify the designed performance and structural adequacy of the cladding system.' We proposed and carried out a number of tests simulating wind load with aggregate bags on 28-day-old units, none of which have failed.

This may be a contradiction of what I said about local engineers earlier but this very visual test satisfied the authorities.

Figure 5

- Theoretically, it has been more difficult and the absence of a single tell-all reference book has proved to be a Pandora's box:

  We have indeed designed GRC cladding with very different assumptions:

  - Using the working stress approach, comparing the service load effects with the Cem-FIL allowable stress, assuming the effect of shrinkage and temperature variation, induced no stress as the fixing did not restrain the panels in their plane.
  - Using the limit state approach, comparing the ultimate load effects with the Cem-FIL stress divided by material factor, and deducing an arbitrary nominal value for shrinkage stress.

This will hopefully be resolved now that the GRCA has published its 'Practical Design Guide'.

Weathering

- A varying degree of attention is paid by architects to detailing and we have to promote the use of good water drips, slopes and draining to avoid bad publicity even when we have to cover the additional cost.

This is an example where the architect's requirement for a parapet capping with a part sloping outwards followed by a curved fascia was creating a perfect dirt path for water marks. We have introduced a water drip and formed the joint to provide a secondary break of the flow.

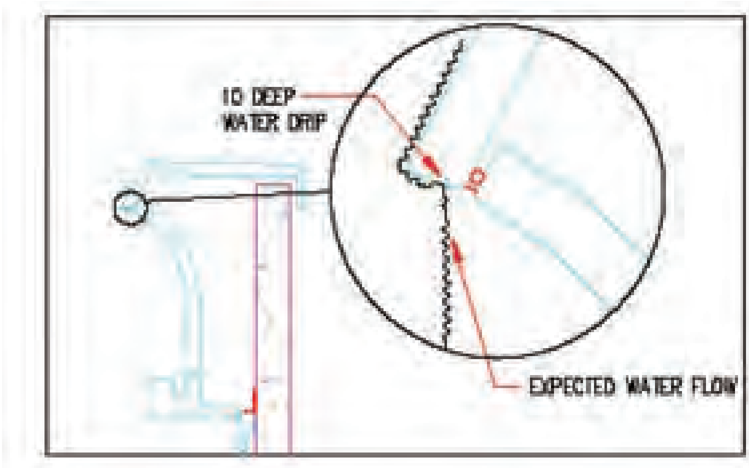

Figure 6

On the other hand, we have to answer unjustified concerns about water permeability. Even though everybody now understands there is no risk of corroded reinforcement, some consultants still need proof that GRC passes concrete or cast stone permeability tests.

To quell these fears, we have also used expensive surface sealers, even when the GRC cladding is acting as a rain screen.

- Most architects are also very worried about using textured finish (fearing the pollutants ever-present in Hong Kong skies will adhere to the etched face) while they don't hesitate to specify white colour finishes that require expensive white silica sand and titanium dioxide pigment.
- Maintenance, which we have to specify in the handover document, is not always followed on private buildings but we take pride in ascertaining that GRC-clad buildings weather better than others in Hong Kong.

Fire properties
Again, while we have never been asked to carry out these tests on our concrete mixes, even when they are loaded with admixtures, the fire-resistance of GRC is always queried and we had to carry out tests on our own very special mix:

39% Cement
39% Silica sand
13% Water
5% Fibre
1% Plasticiser

JOINT DESIGN

Joint width
This is also not a Hong Kong-specific issue of course. While we have had to remind some architects of the dangers of using joints that are too small, we are not making it a GRC-specific issue anymore.

We initially used the high end of the range given in the Cem-FIL and PCI design manuals (1–1.5mm/m) then lowered it to 1mm/m based on a study made by Cem-FIL(2).

To crosscheck, we now have the new BS-EN 1170-7. We understand the decision on the inclusion of this test within the list of test methods was in the context that problems with GRC panels in the 1980s were almost entirely due to shrinkage or expansion effects, which were not catered for in the design. It is also a useful test for evaluating new mix designs but we decided to carry it out as a regular QC test.

Since we started testing, results have been very consistent, about 0.3mm/m for shrinkage and 0.3–0.6mm/m for expansion.

We have also measured the longest panels we are casting now (9.5m-high pilasters for the Wynn Resorts' project in Macau) on demoulding, at 7 and at 15 days.

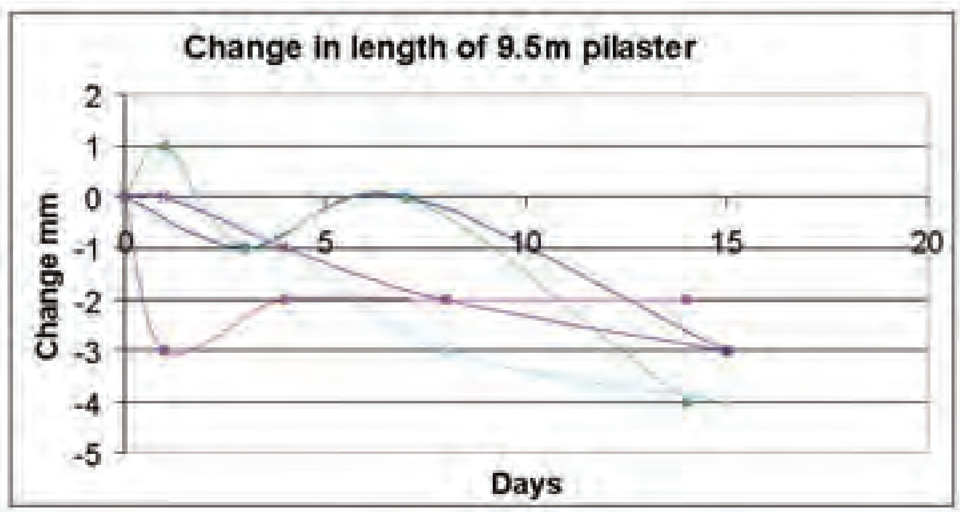

Figure 7

The maximum initial shrinkage is 4mm, that is 0.4mm/m. We understand, however, that the shrinkage measured may be reduced partially by a stress in the flex anchors.

These results have reduced the significance of this aspect of performance as we now understand that the extreme reversible movement likely to occur in the life of panels exposed to the Hong K ong weather is well below 1mm/m.

Long return
This is a requirement from architects for which we have found no magic answer. While with precast concrete cladding we do use turning tables with a construction joint, the thin facing mixes used in GRC have prohibited this solution and we usually limit the returns to 300mm.

Figure 8

Figure 9

Open joints vs. sealed joints
We have used both types on different projects and each one had its difficulties:

Rain-screen cladding (used, for example, at Cityplaza)
- Drainage of the water going behind the panels can be problematic
- Problems with soffits where the waffle pattern makes an ideal trap for water that will very slowly seep in and affect the colour of the panel
- Water penetration past secondary barrier at cross joints.

Sealed joint
- Type of sealant (one-part vs. two-part, primer requirement)
- Adhesion test
- Performance dependence on workmanship

We also have regular discussions with the architects on what the joints look like at returns against window/door frames to avoid over-exposing the waterproofing material.

MIX DESIGN

Facing/GRC
Using concrete facing mix, we had delamination once at the very beginning for Cityplaza Tower. We solved the problem by increasing the cement content of the facing mix and grading the sand.

A close monitoring of the sand supply (both silica sand and CRF) has eliminated this problem.

Polymer
Polymer mixes were 'imported' when Redland set up its GRC operation. However, the hot climate was a problem with very quick setting of the matrix as shown by this failed slump test (Figure 10).

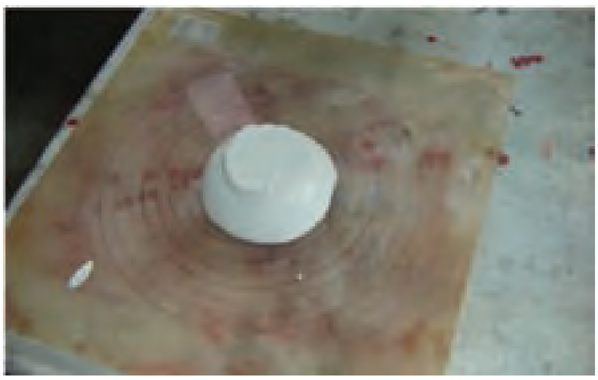

Figure 10 - Failed slump test, caused by very quick setting of the matrix in the hot climate

We sent some samples of our cement and sand to Forton who advised on a particular plasticiser but, regardless of the fact that the same product had different names in Belgium, the UK and France, it was not available in Hong Kong. We carried out trials with all the superplasticisers, different polymers and air-entraining agents but got nowhere and ended up using non-polymer mixes.

Having ambient humidity of over 90% for 8 months of the year and temperature above 20°C for 10 months of the year also helps natural curing.

FIXING DESIGN

Reduced distance between panel face and wall

Given the thirst for buildable sites in this congested island, this is a constant argument with architects. Developers want to use every precious inch of terrain they have bought. The cladding is designed to be right on the boundary line and we cannot move it away from the walls.

This problem was compounded by the fact that, until recently, Hong Kong Building Regulations stated that the calculation of the GFA (Gross Floor Area) had to include the non-structural cladding.

However, it is difficult to ask big clients to compromise and we recently needed 2 months to convince one that it was impossible to fix a 6.5m-long panel with its face at 100mm from the supporting wall.

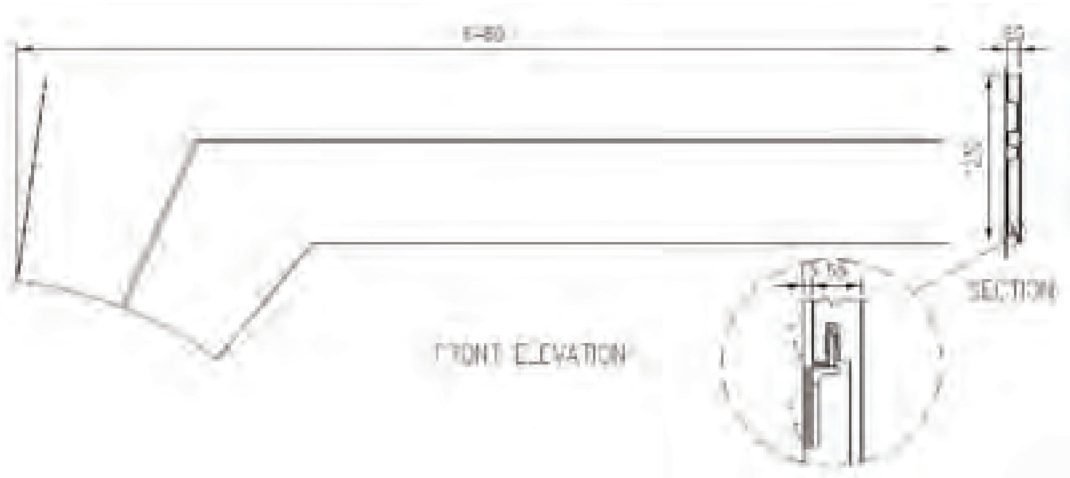

Figure 11

Cast-in sockets (or ferrules)

We have carried out numerous tests on sockets cast in thin-walled GRC both in tension and shear. The tests were carried based on the BS 5080 for 'Structural fixings in concrete and masonry'. The results were generally very similar to the values in concrete given by the fixing manufacturers.

Figure 12

Support bracket in a GRC slot (or pocket)
For most dead load support, we employ the commonly used non-accessible 'bracket in a slot (or pocket)' fixing. We were asked on a recent project to carry out tests to support our design assumptions. The test specified was to the ASTM C1354-96: 'Standard test method for strength of individual stone anchorages in dimension stone'.

The results were OK but the problem came when the Engineer asked us to calculate the characteristic value of the capacity of the pocket design. (We had carried out only 10 tests, so the 'acceptability index' was 2.36 and then dividing the result by the 1.8 material factor, the 1.4 ageing factor (assuming the long-term ultimate tensile strength (UTS) will reduce with age (in the same fashion as the MOR) towards the short-term bend over point (BOP) value), and 1.4 load factor.)

From the average failure load of 15.35kN, we were reduced to 2.9kN allowable working load (that is a global factor of 5.3). This was also much lower than the calculated capacity of the slot using the 1MPa 'punching shear' capacity mentioned in the design guide and used on previous projects.

We have even used a structural analysis program to model a panel and check the maximum stress.

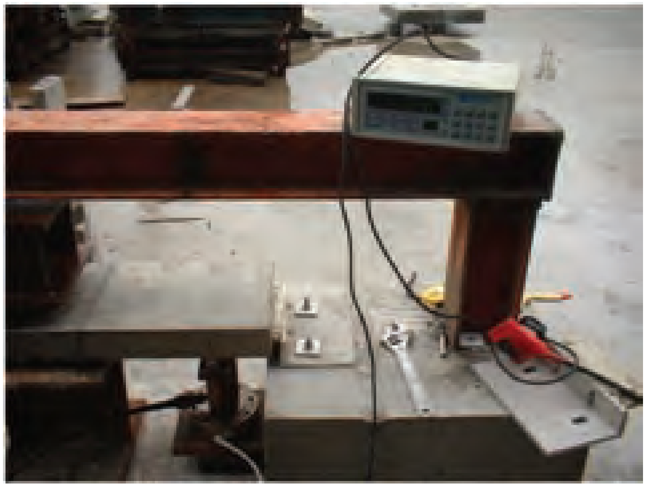

Figure 13

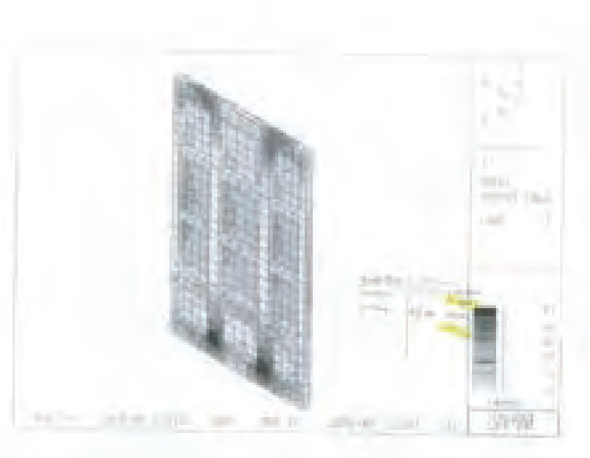

Figure 14

Epoxy-embedded dowels
For small units, copings and skirtings we have used threaded studs or small steel reinforcement bars cast in the GRC units. These units are then 'offered' in holes filled initially with an epoxy.

Cast-in channels
We have used cast-in channels on a relatively limited number of projects. There are many reasons for this but the main one is that, as with everything else in Hong Kong, the fast-tracking nature of most projects means that the supporting structure is usually cast before we are given the opportunity to design the fixings. In one project actually, the contractor cast in all the channels based on a stone grid. When the client changed its mind and decided to use larger GRC panels, we designed a secondary steel frame attached to the cast-in channels to pick up the GRC panels.

Figure 15 shows one of the elevations showing the amount of steel that was fixed onto the reinforced concrete wall.

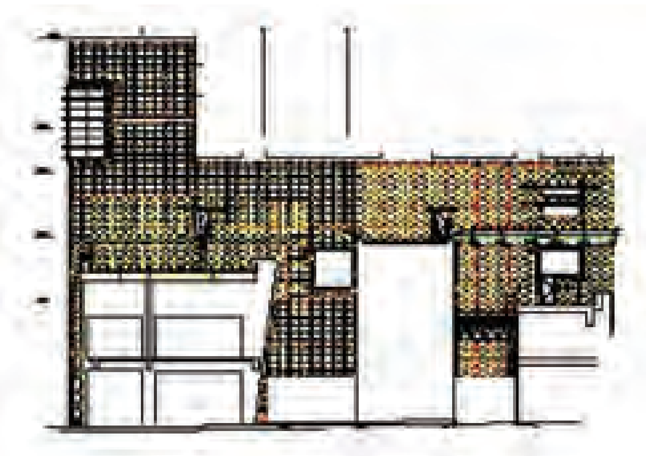

Figure 15 - One of the elevations showing the amount of steel that was fixed onto the reinforced concrete wall

Invisible fixings

Besides the obvious answer to this requirement (I know you can't see it but it is there, it is just 'invisible'), we are regularly asked to design hidden fixings for panel replacement, smoke vents, maintenance access panels, fire service inlet doors and even full-size doors).

MOCK-UP, PROTOTYPE, BENCHMARK

Whatever the name used, there is generally some confusion in the different parties involved as to what exactly is the purpose of the 'mock-up'.

Whether it is to judge the finish, the interfaces or particular shapes and sizes of mouldings, it should be built well in advance of the actual project. However, this is rarely the case in Hong Kong and most mock-ups have to be perfect the first time round as full-scale production is on-going before they are accepted by the clients.

However, there is a case for models such as we have used for a Hindhu temple in Auckland, New Zealand.

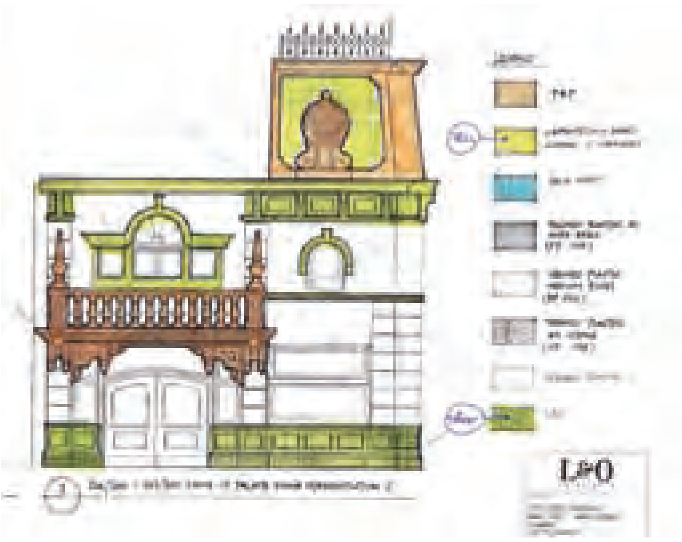

Figure 16

Figure 17

The Disney Hollywood Hotel (Figure 18) mock-up combined five different full-scale panels (internal corner, curved return, roof panel). It allowed the architect to correct minor design faults (that the non-architect would not notice) and to improve the installation method.

Figure 18 - Disney Hollywood Hotel

Figure 19 shows a small model we made for the Disney design executives to see the crispness of the edges we can make.

Figure 19

Figure 20

For our latest job, we submitted four full-scale panels to a 7-day regime of four cycles per day. Each cycle consisted of heating (above 50°C), cooling (below 10°C), wetting and drying. Trevor Gregory details some of the results in his paper(3) but the client was satisfied that 'the appearance of the panels, in particular the uniformity of flatness and finish over ribs and edge stiffening, was not affected in predictable extremes of temperature when wet and dry'.

However, we still had to build an 80-panel benchmark (see above). Again, the client was happy with the GRC and this building will no doubt figure in the GRC Hall of Fame.

CONCLUSION

The past 10 years of effort put into convincing the local authorities and consultants that GRC is indeed an excellent material for cladding find their reward today, with the realisation of this conference here in Hong Kong.

Hopefully the publication of the new GRCA 'Practical Design Guide' will do the talking for me from now on.
I also trust that all designers will keep in mind and live up to our motto:

GRC gives architects design freedom

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