

Application of light-weight GRC cladding panel in Nanjing Youth Olympic Conference Centre

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Abstract

As a flexible curtain wall material, the light weighted GRC wall panel has been attracted an extensive attention in the field of architectural design and curtain wall. Focusing on the application of such panels for Nanjing Youth Olympic Conference Center, which is also the first large scale application for modern digital construction, this paper elaborates some practical thoughts and methods in product design, manufacturing and installation for this project.

INTRODUCTION

Nanjing Youth Olympic Conference Center, located at the north of the Jiangshan Street, Jianye District, was built and put into use for the World Youth Olympic Games in 2014. It covers about 400, and is composed of a conference center of 6 stories, a five-star hotel of 68 stories and a meeting hotel of 58 stories, at the height of 46.9m, 314m and 249.5m respectively. The two towers are connected to the conference center via two corridors at 15m and 21.12m separately [Figure 1].



Figure 1. Impression drawing of the Youth Olympic Center

The project was designed by Zaha Hadid, a famous Architect in deconstructionism. Inspired by a sailing boat, she designed it like a space yacht [Figure 2], meaning that the Youth were setting out their voyage and riding the winds and waves bravely. A bird's eye view of the building is really like a space yacht coming from an outer space due to its strong sculpture. However, one may have different images when viewing at different positions.



Figure 2.. Impression drawing of the Youth Olympic Center

Design of curtain wall

Because of the irregular and complex construction structure, it was the most difficult project in the world, far beyond the difficulty for the Beijing National Stadium. Most of the steel elements are connected in an inclined way and the total consumption of the elements reached 45,000 tons. All of the steel elements are in different shapes, sizes and weights. The conference center is cladded with more than 12700 different shape GRC panels, while for some area of the tower wall, there are more than 4000 pieces GRC panels.

Design scheme

The project is made by complex steel structures, like a stool, whose four legs are independently constructed from the ground but gradually connected together between the locations in the height of 21m and 27m. Therefore, the perpendicular GRC elements are only used around the elevators. Such kind of “stool” structure [Figure 3] avoids the pillars and guarantees the function and integrity of the whole building.

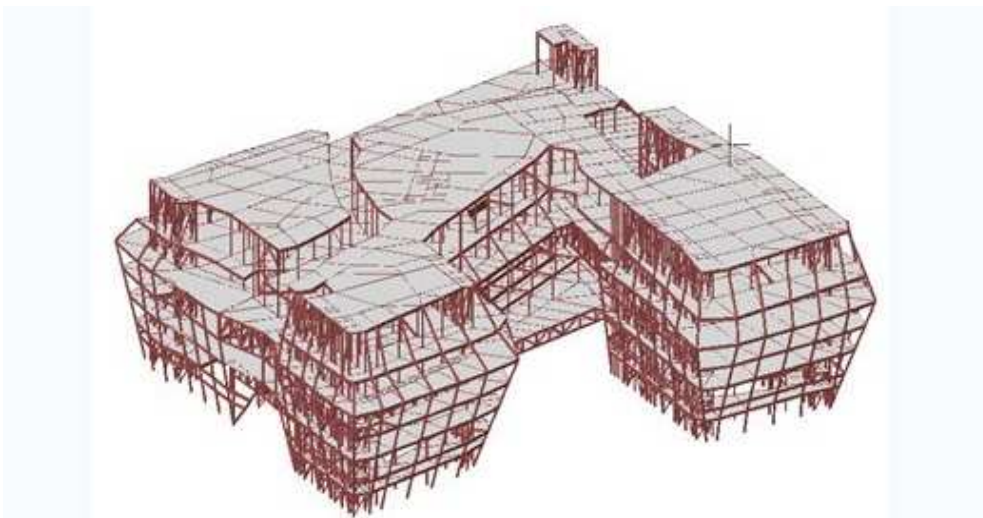


Figure 3. Sketch of the podium building

When the design scheme and the building structure were finalized, the selection of wall cladding materials became the crux of the detailed design. In order to meet the requirements of the impression drawing and the tight project schedule, after a series of wall materials researching, the answer came out, the light weighted GRC panel was finally selected and used for Nanjing Youth Olympic Stadium due to its light weight, high strength, fast fabrication and easy installation as well as sound performance in displaying architectural appearance.

Nanjing Beilida New Materials System Engineering Co., Ltd is a professional manufacturer of GRC wall panels in design, development and fabrication throughout the whole world. There is has an excellent design team for the company. After the detailed discussions with the experts and designers of Zaha Hadid Architects, China Architecture Design Institute Co., Ltd and Shenzhen Hua Sen Curtain Wall Consultation Co., Ltd, it was decided that the walls of Conference Center and the Twin Towers (from the location of lower than 76 meters) would be cladded with irregular light GRC panels, approximately 110,000 in total. It was an unprecedented application in the larger irregular building structure. The detailed design was mainly undertaken by our excellent designers. When receiving the building drawing and the Rhino 3D Model from Hua Sen Design Institute, our designers immediately carried out the relevant design works including installation scheme, panel division and shape design, secondary structure design, joints and brackets position design, product steel structures design, panel design and mechanical calculation.

Appearance design

In order to express the appearance and culture connotation desired by the Architect, making samples was the most important at the beginning. On one hand, there was no real confirmed sample that the Architect can refer to, therefore, the tests and adjustments should be conducted successively by referring the requirements of the Architect and project leaders in Jianye District of Nanjing City; on the other hand, the color and texture of the samples should be in line with that of the real GRC products and within the limitations. Therefore, the sample maker should thoroughly understand the requirements of the Architect and the owner, so that he/she can get a better understanding of the appearance. Only based on these can a sample be made to express the desired appearance [Figure 4] and realize the design intention.

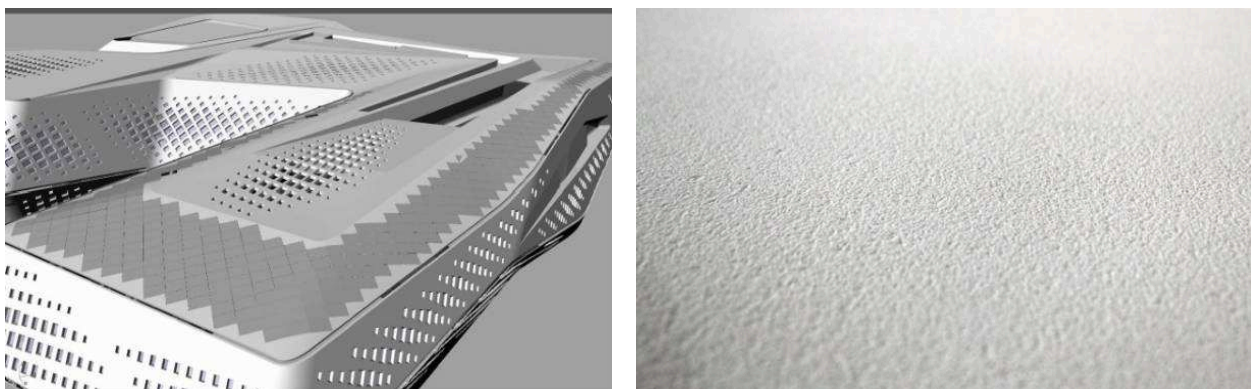


Figure 4. Scaly appearance and GRC wall panel texture

GRC wall panel design

Panel profile design

Because of the complex building profiles, multiple structure conflicts and connections were found many during the detailed design. In order to fully express the building spirit and integrity, the GRC panels were designed and classified into four types which were 40,000 of flat panels, with the normal size is 3mx2m and the maximum is 6mx3m; 32,000 of folded panels, the normal size is (2+2)mx2m and the maximum is (5+2)mx3m; 30,000 of double curved panels, the normal size is 3mx2m and the maximum is 6mx4m; 8,000 of single curved panels, the normal size is 3mx2m and the maximum is 6mx4m.

The panels were designed to be installed in an inclined line both for roof and walls, while the exact space for the installation of window glasses must be reserved. Considering the durability and mechanical safety, the panel thickness was finally designed at 15mm in accordance with the mechanical calculation during the profile design. The weight of the GRC panel is controlled at about 50kg/ , including the weight of product support steel structure. Such kind of GRC panels are really very thin but of high strength.

Node design

The flat panels are designed and installed by connecting the product support steel structure with main truss purlin via bolts. Figure 5 shows the typical detail installation nodes.

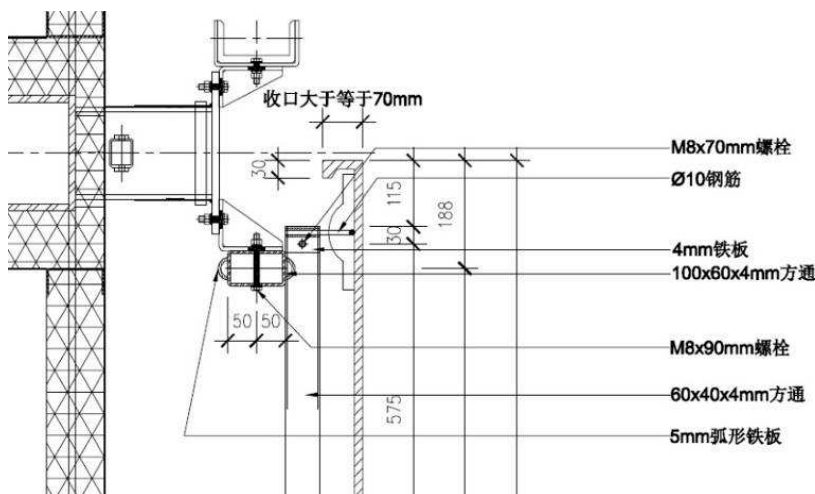


Figure 5. Installation nodes of flat panels

The folded panels are designed and installed by connecting the product steel structure with the secondary joist. Figure 6 shows the typical installation nodes of the folded panels. On the building main steel structure, the secondary joist is installed, which is connected to the pre-installed brackets on the steel structure of the GRC product and further fixed by bolts.

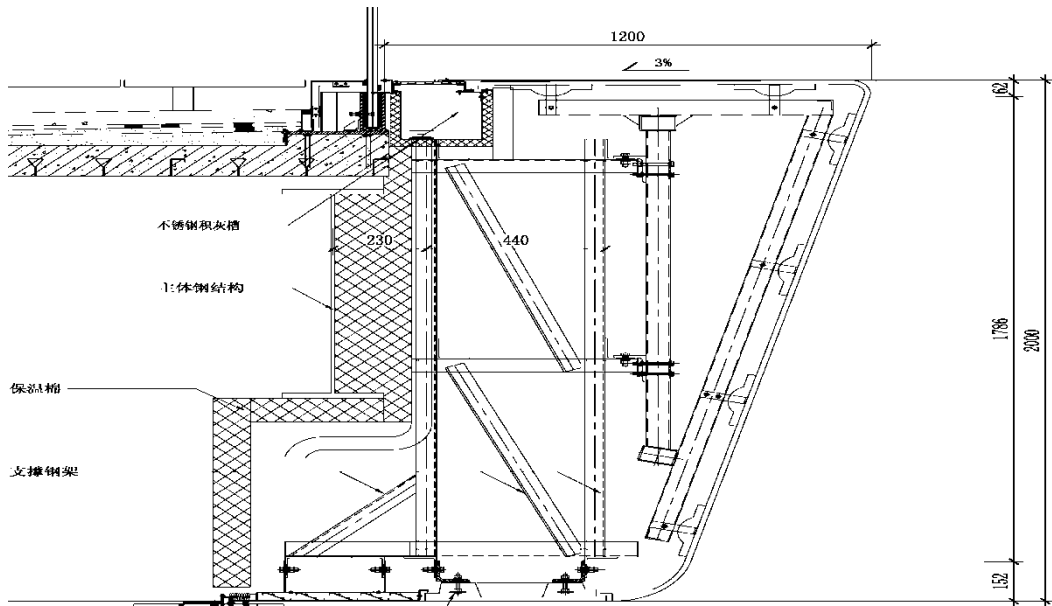


Figure 6. Installation nodes of folded panels

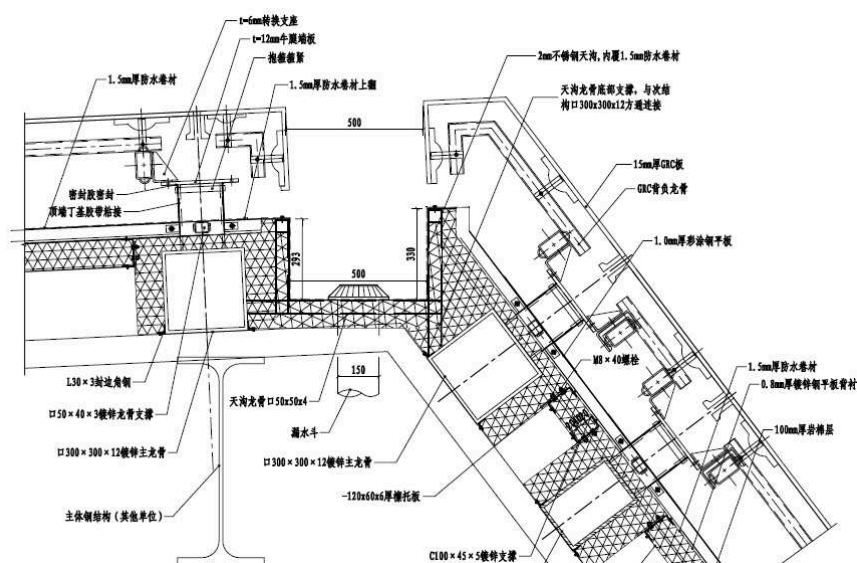
Product steel structure design

The material and design of the product steel structure are different as per panel profiles. The steel structure of folded panel was designed in a triangle profile, so that it could be connected to the panel backside in an “L” shape, preventing the panel damage due to local stress concentration. While the steel structure of flat panel and curved panel was designed in a planar structure and connected to the panel backside in the same way as that of folded panels [Figure 7], but was installed to the longitudinal girder.



Figure 7 Connection of steel structure with the GRC panel backside

For the design of the roof waterproof engineering, stainless steel water chutes were installed at the bottom of the GRC panel, which connect with gutters, so that water can be drained [Figure 8]. For a perfect waterproofing, a waterproof system was also provided under the GRC panels. A combination method was used for the waterproof of panels between each floor, i.e. firstly, the connection gaps were designed in tongue-and-groove and are glued, in addition, a waterproof system was provided, which guarantees a good waterproof function of both the floors and cornice.



Mechanical calculation

Table 1 GRC physical properties

Force types	Description	Value
Compression strength	Stress	12 N/
Flexural strength	GRC panel face	6 N/
Tensile strength	Spraying	4 N/
Tensile strength	Premixed tension	3 N/
Bending strength	Box and channel profiles as well as GRC ribs	4 N/
Shear strength	Shear position	1 N/
Modulus of elasticity		15000 N/
Density		2000 Kg/

Load

Wind load

The basic wind pressure in Nanjing in 50 years = 0.45 KPa

Building height = 46.1m

Gust factor B class roughness = 1.59

Height coefficient = 1.66

For the safety reasons of building envelop, the shape coefficient is 2

Characteristic value of wind load:

$$\begin{aligned} F_w &= 0.45 \times 1.59 \times 1.66 \times 2 \\ &= 2.4 \text{ KPa} \end{aligned}$$

Snow load

Basic snow pressure in Nanjing in 50 years = 0.65 Kpa

For safety reasons, distribution coefficient of snow load is 1.2

Characteristic value of snow load:

$$\begin{aligned} F_x &= 0.65 \times 1.2 \\ &= 0.54 \text{ KPa} \end{aligned}$$

Dead load

Dead load, GRC density is 2000 KG/, the face load is 0.24Kpa based on 12mm

The total load is 0.6Kpa if the steel weight is included.

Live load

Live load for inspection = 1.0 KPa

Seismic load

Seismic fortification intensity = 7

$$F_{eq} = \dots / A = 0.08$$

The face load is $60 \times 0.1 \times 0.08 = 0.48 \text{ KPa}$ if the weights of 15mm GRC and stud frame are included.

Load partial safety factor and load combinations

1.35 dead load + live load (dead load control)

1.2 dead load + 1.4 live load (live load control)

1.35 dead load + 1.4×0.7 live load $\pm 1.4 \times 0.6$ wind load (dead load control)

1.35 dead load + 1.3×0.7 live load $\pm 1.4 \times 0.6$ wind load (live load control)

1.35 dead load ± 1.4 wind load + 1.4×0.7 live load + 1.4×0.7 snow load (wind load control)

1.2 dead load + 0.6 live load ± 1.4 seismic load ± 0.28 wind load

Deflection control

Deflection control is mainly used for GRC frame; therefore, the deflection inspection is done in sap

$$\begin{aligned} f &= 9.2 \text{ mm} < 1900/250 \\ &= 7.6 \times 1.4 \\ &= 10.64 \text{ mm} \end{aligned}$$

Because the GRC panels in this project are far larger than the normal sizes, therefore, for the safety and easy fabrication reasons, the mechanical calculation for the GRC installation becomes the first and foremost issue. Our professionals carried out a series of rigorous calculations in accordance with the relevant domestic and international design regulations and specifications by considering the engineering wind load and seismic fortification intensity. All kinds of the mechanical calculations are done at different positions and on different panels [Figure 9] to make sure that the safety factor is above 1.5, which is higher than the other curtain wall materials.

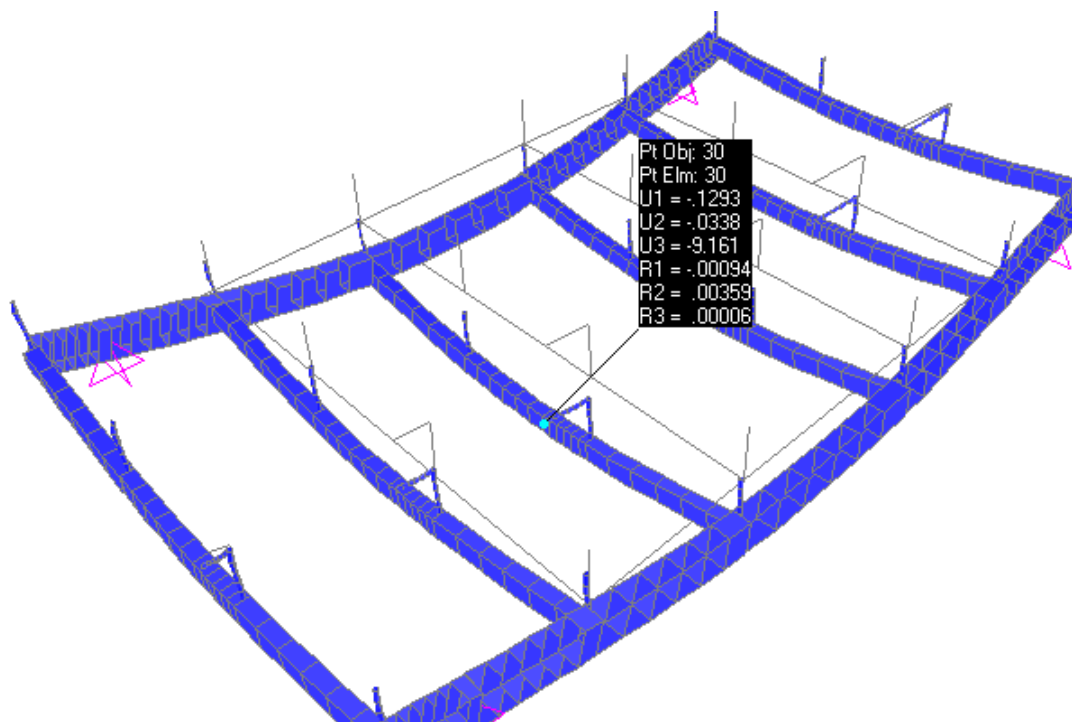


Figure 9 Sketch of mechanical calculation

FABRICATION OF GRC WALL PANELS

Material

GRC products are characterized by good advantages of light weight, high strength and sound fabrication performance. All of the raw materials and fabrication processes are in line with the high requirements of the international and European industrial standards. The imported white cement is used in the production, its whiteness is higher than 90% and the strength is 42.5. All the aggregates during the production are composed of the good quartz sand with the content of larger than 96%. The glass fibers are alkali resistant with the content of is higher than 16%. For the durability and good mechanical strength, some good additives bought from Rohm and Haas, BASF and Sika are also used in the fabrication. All of the raw materials used in the production are in line with Precast Concrete Institute (PCI) GFRC recommendation specifications. After a series of tests, it is decided that the cement sand ratio is 1:1, water cement ratio is 0.38 and the fiber content is 5%. Due to these reasons, the products not only can express the designed

sculpture and color but also meet the good product indexes detailed in the European industry specifications. In line with the Chinese standard, only the good steel rectangular pipes are used for the fabrication of product steel structure. The structure is welded in accordance with the welding specification and later on hot-dip galvanized by more than 70um, delivering a good performance of anti-corrosion for at least 50 years.

Mould fabrication

In order to guarantee a precise panel connection, larger molds fixed on the ground were used for the fabrication of larger double curved panels. CNC digital carving machine [Figure 10] was used for creating the exact complex profiles on the surface of the larger curved panels [Figure 11].



Figure 10 CNC digital carving machine



Figure 11 GRC mold fabrication

Manufacturing process

Typically, the GRC manufacturing process begins with the mold fabrication and followed by raw material batching and mixing, after these steps, the mixed slurry coupled with the chopped alkali resistant glass fiber (usually 30mm in length) are sprayed layer after layer with a spraying machine. The compaction with rollers should be provided at every time the slurry is sprayed. When the thickness is inspected and reaches the designed value, the mold together with the slurry should be placed standstill for curing. The product can be taken out of the mold when reaching the certain strength after curing for a period of time. Because of the unique building structure, the three-dimensional digital model was successfully applied in the fabrication process in this project, overcoming the difficulties in mold fabrication, product size control, precise panel connection, and 3mm error limitation. Thanks to such kind of technology, the installation error of the product steel structure was well controlled and could be removed by adjusting the brackets. Due to the technological innovation and equipment improvement, we successfully resolved the technical difficulties in product demoulding, handling and installation [Figures 12-14].



Figure 12 GRC spraying production line



Figure 13 Overhead cranes used for product handling



Figure 14 Fine treatment of product surface

Quality control

The product quality assurance and quality control are in line with the ISO 9001 quality management system and Precast Concrete Institute PCI-130 Specification. For the quality assurance and control, a dedicated quality department with tens of professional inspectors is founded to guarantee the quality of raw materials, molds, fabrication process and final products. In addition, a test lab is used for the random inspection of products produced by different shifts everyday. Finally, in order to find out the quality problems at the exact step, every piece of GRC panel was designed with a unique digital identity, based on which we established a detail product quality record. Thanks to this perfect quality management system, the product quality is well guaranteed.

The main physical and mechanical properties are listed in Table 2.

Table 2 GRC physical and mechanical properties

Item	Index	Real value
Ultimate ratio of flexural strength, MPa	≥ 7.0	9.2
Ultimate flexural strength, MPa	≥ 18.0	22.6
Impact resistant strength, kJ/	≥ 8.0	15.6
Bulk density (dry density), g/	≥ 1.8	2.0
Absorption, %	≤ 14.0	7.5
Freeze-thaw resistance	No split or delamination after 25 cycles	50 cycles
Retention of ultimate flexural strength (80	≥ 70	81

INSTALLATION OF GRC WALL PANELS

Installation of steel supports (same as the secondary joist/structure mentioned above)

In order to connect GRC steel structure with the building main structure, steel supports should be installed, which were designed by the GRC supplier by referring the drawings of the building main structure. The roof steel supports were composed of truss purlin and brackets, which were made and installed to the roof main truss by the installation company in accordance with the design drawings. The steel supports between every floor were designed in a box profile at a certain length and welded to the building main steel structure.

Installation of products

Installation of roof

Firstly, the purlin system of the roof steel supports was installed as per drawings. Secondly, the larger GRC panels were lifted and installed either from ridge and cornice down to the ground or in a reverse order [Figure 15]. Later on, the main connectors of the panels and purlin system were fixed by referring the orthostichies. Finally the panel position adjustment and gap adjustment were done by taking advantage of particular gauges. Water chutes were installed at the back side.



Figure 15 Panel installation on roof

Installation of wall panels between floors

The steel supports and the building main structure were welded first by considering the precise installation positions. Later on, the products were lifted and fixed at the exact installation positions [Figure 16]. When the installation work finished at a certain area, the position adjustment was carried out to guarantee an even gap between products.

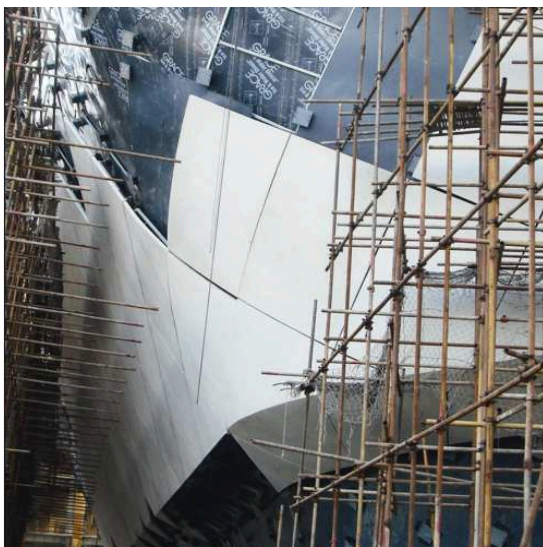


Figure 16 Panel installation between floors

Error adjustment and quality control

In theory, the installation precision can be guaranteed, because the 3d Rhino model was applied throughout the project design and completion. Due to the uncertainties in the construction, error adjustment should be carried out throughout the whole installation so as to make sure the building profile and product joints are consistent and beautiful [Figure 17]. Thanks to the sound cooperation with the bureau of CSCEC, we made a good control of the construction process, so that the project featured with great difficult and short time was carried out and completed successfully.

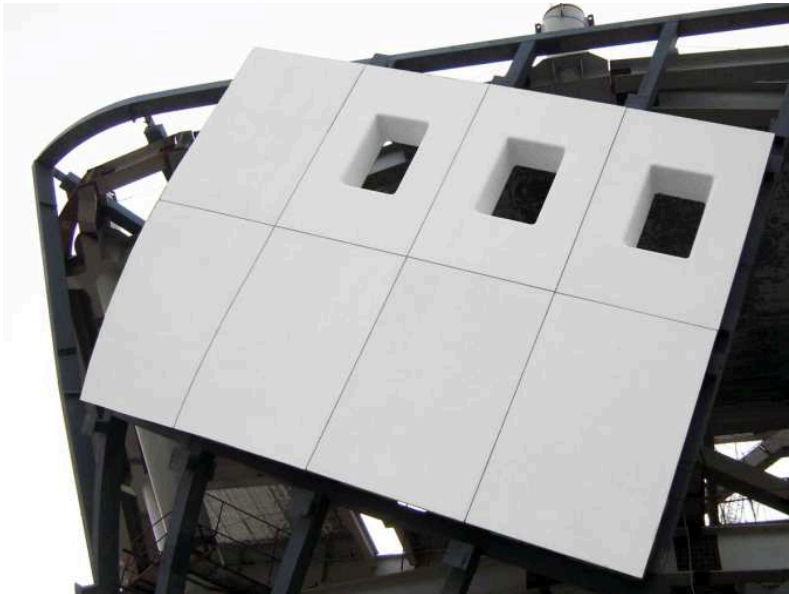


Figure 17 Installation joints

GRC PANEL SURFACE PROTECTION

The surface protection of GRC panels has been the key concern of GRC experts. By applying the protection, not only the waterproof function and self clearance function can be provided, but also product color and matt granular texture can be maintained in a long period. Based on a series of experiments [Figure 18] and careful considerations, an advanced inorganic hybrid silicone-acrylate emulsion was finally selected for protecting GRC panels. During its curing process, an inorganic volatility will release inorganic chemical compound which will migrate to and form a coating on the surface of the panel. The protective agents are characterized by good hydrophilic ability and resistance against photo catalyst corrosion.



Figure 18 Comparison of different protective agents

CONCLUSION

The final appearance of the project is shown in Figure 19. The application of light weighted GRC wall panels in Nanjing Youth Olympic Conference Center, the first large-scale application for the modern stadiums, signifies that China is a leading country in concept innovation, technological development and engineering application. With the development of individuality and digitalization in building designs, the light weighted GRC wall panels will definitely make greater contributions to the building design development just as what is demonstrated from this project. If the relevant National Product Executive Standard and Construction Specification can be issued soon, I believe that the GRC panels, featured with good functions, intelligence and environmental protection, will play a more important role in the constructions.



Figure 19a. Completed project

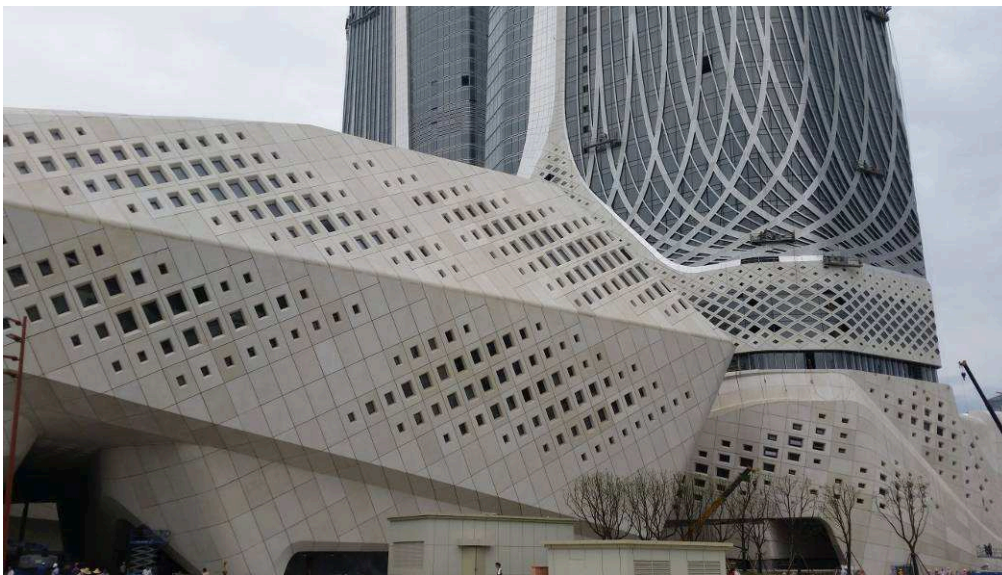


Figure 19b. Completed project



Figure 19c. Completed project

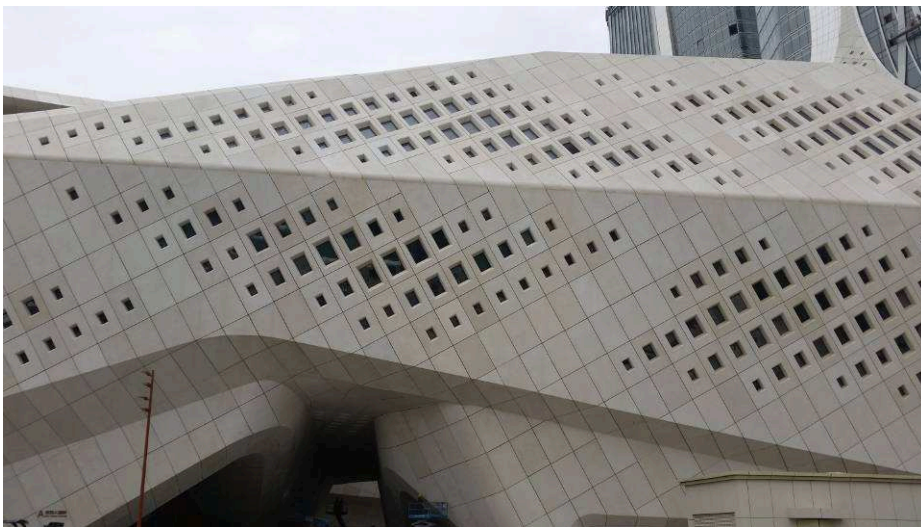
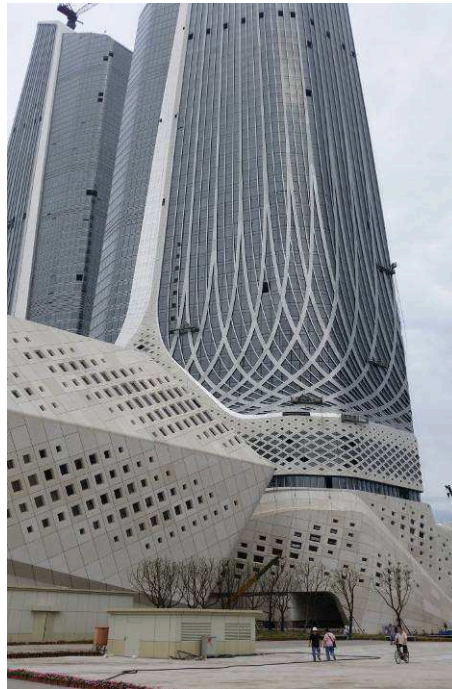


Figure 19d. Completed project



Figure 19e. Completed project

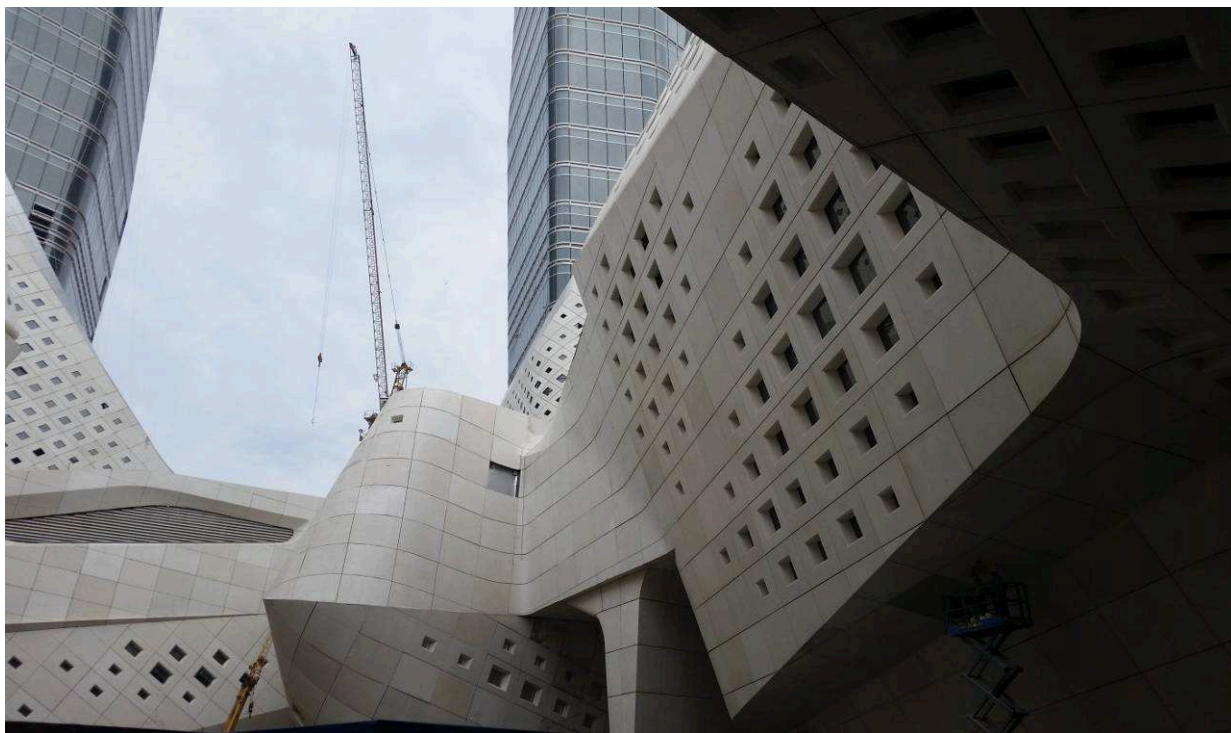


Figure 19f. Completed project