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# Primary Composite Structures, Very Large Conference Hall Roof at Library Project, Bahrain – A Case Study

By

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## Abstract

The paper presents a case study of a very large, long span roof structure developed for a Conference hall & Library Building at Bahrain. The roof comprised of five vaults as primary structural composite elements. Each vault has a length of 50m with 7m further cantilevered overhang. The front Face is of 16m width by 9.25m rise. The rear face is of 8m width by 6m rise. Each vault comprised of six panels, joined together by flange bolted connections. Panels were manufactured in reinforced concrete moulds. Special CAD designed CNC cut timber templates were used to set up the panel profile in the mould. Manufacturing was done under strict quality procedures. Roof structure of this size in conventional materials like steel or concrete would have imposed very high dead weight on the building structure and the footing. Actual weight of one FRP composite vault assembly is about 30 tones. A similar concrete or steel structure would have been 30 to 50% heavier. The project location is on a waterfront. The Installation is at an elevation of 28 m above ground level. Wind loads due to gust of 120 kmph and a temperature variation of $15^0$ to $50^0$ C were considered. The FRP Roofing project programme of conceptual design, detailed engineering, tooling, manufacturing, assembly and installation at site was completed within 16 months.

Figure1.

## Introduction

FRP Composites provide practically maintenance free structures by virtue of their inherent characteristics of:

1. The ease of moldability
2. Integration of complex shapes into monolithic panels.
3. Dimensional stability against temperature variations.
4. High load bearing capacity at a relatively low weight (high specific strength and stiffness),
5. Very good thermal insulation.
6. Complete resistance to environmental corrosion, even in extreme conditions.

The concept of fully structural roof system in fiber-reinforced composites was initially discussed by the architects with the designers in 1999. The concept was further developed by the designers and manufacturers with the architects in December 2004 for conference hall building in Bahrain.

The roof system comprised of five vaults as a primary structural composite elements. Each vault has a length of 50m with 7m further cantilevered overhang. The front Face is of 16m width by 9.25m rise. The rear face is of 8m width by 6m rise. This is one of the largest composite structures for roofing application globally. Manufacturing was done under strict quality standards under ISO 9000 procedures by the manufacturer. Such a big structure in conventional materials like steel or concrete would have imposed tremendous dead weight on the reinforced concrete substructure and on the footing and may not have been economically viable solution. Advantages of FRP composite were creatively employed by designing and constructing fully structural lightweight composite roofing system for this project.

## Analysis and Design

Vault dimensions were determined by the architectural requirements. The massive structure is prominently seen from the nearby waterfront and from across the bay. Hence aesthetics was the one of the primary objectives. For ease of molding and handling, each vault was split into six sections, joined together by bolted flange connections. The front fascia of each vault was provided with a decorative design, which was integrated with the fascia panel, rendering structural stiffness to the panel.

Figure 2

Structural analyses were carried out using finite element technique. Initially the panels were modeled using 3-D general shell elements with six degrees of freedom. The deflections and stress patterns were identified. During the detailed engineering stage, macro mechanical analyses were carried out to arrive at the laminate design i.e. number of layers, lamination sequences and angles. The final FE model was built using 3-D laminated composite general shell elements. The static analyses were carried out for various load cases like superimposed load of 1.2 kPa, wind load with maximum wind speed of 120 kmph and thermal loads considering, $T_{min} = 15^0$ C, $T_{max} = 50^0$ C. Each vault was considered as a stand-alone item supported on the steel trusses along the length. The anticipated deflections in the support structure under different load cases were also considered in the analysis in order to optimize the steel support structure.

Figure 3

The limiting states of design, for deflections and stresses, were set up as per guidelines provided by the "Structural Design of Polymer Composites - EUROCOMP Design Code and Handbook" ( Ref. 1). Laminate characterization was done with testing at a third part laboratory for mechanical properties like Tensile and flexural strengths, Modulus etc.

## Material Specifications

Reinforcement- Combinations of different forms of E-glass reinforcements like chopped strand mat (300 GSM) and woven roving (800 GSM) were used.

Resin- In order to meet the fire safety requirements fire retardant polyester resin system meeting requirements of BS 476 Part 7 to Class 1 was used.

Core material- Structural honeycomb core was considered in sandwiched laminate construction.

Laminate Structure: Honeycomb core sandwiched between fiber- reinforced composite skins. Open contact moulding manufacturing technique with minimum of 35% of fiber content.

For lay-up design, actual material characterization was done for mechanical properties to be considered in the analysis. The governing Tensile Strength of the laminate was 175 MPa and the allowable deflection limit was Span/150 for inaccessible roofs.

## Manufacturing

Each vault was split into six panels for ease of handling. All panels were of approximately equal weight. It was not practical to transport panels, with developed width upto 13m by length upto 21m from factory to site. Hence the panels were molded at site. Manufacturing facility was set up at site under strict quality procedures as per ISO 9000 norms followed at BFG International Ltd. Special CAD designed CNC cut timber templates were used to set up the panel profiles. The mould was constructed in reinforced cement concrete (RCC) with marble finish. Panels were manufactured by open contact molding process with these precision moulds.

Figure 4

Figure 5

## Handling and Assembly

Weight of a typical single FRP panel was about 5 ton. A custom designed gantry and demoulding jig was necessary in order to safely de-mould the panel. Figure below shows how the panels were handled during demolding operations.

Figure 6

Two Panels were assembled on ground with customized assembly jig to form a stable arch.

Figure 7

## Installation

Special installation jigs were mounted on assembled panels. Such assembled pairs of panels, weighing 25 ton including weight of installation jig, were lifted at 30m elevation and mounted in position with 200T and 400T capacity fly jib cranes. The crane positions were predetermined based on location of center of gravity, load to be lifted and maximum possible lever arm of the crane. Adjacent panels were connected with bolted flanges. Base flanges were secured to supporting structure. All flanges were predrilled to precision with CNC cut drill jigs.

Figure 8

## Closing Remark

The installation of single vault took 3 days, including pre-assembly. Each vault of 30-ton FRP weight was lifted to 30 m elevation and installed within tolerance level of +/-3mm, demonstrating advantages of

- Complete 3D CAD based approach
- Use of CNC Cut tooling references
- CNC cut drilling jigs
- Lightweight nature of composite structures for fast installations.

The entire project, from concept design to final installation at site was completed in 16 months. Composites for primary structures are well accepted material in the region. Light weight FRP structure helped the project designers to optimize the building design achieving direct project cost reduction.

## Acknowledgements

We acknowledge entire team of Composite Designs & Technology involved in the process of design and engineering of the roof structure.

We thank and acknowledge BFG International Ltd. Bahrain, manufacturing & Installation contractors who followed our design specifications to perfection. We thank Mr. Mukund Zanpure, project manager and the manufacturing team at site for untiring efforts to make the project a success. Our special thanks to Dr. Samer Al Jishi, MD, BFG International Ltd. for allowing us to use the project data for this paper

## References

1. John L. Clarke, "Structural Design of Polymer Composites -EUROCOMP Design Code and Handbook", Chapman and Hall, London, 1996

**Figure1. Actual site photograph after five vaults are installed**

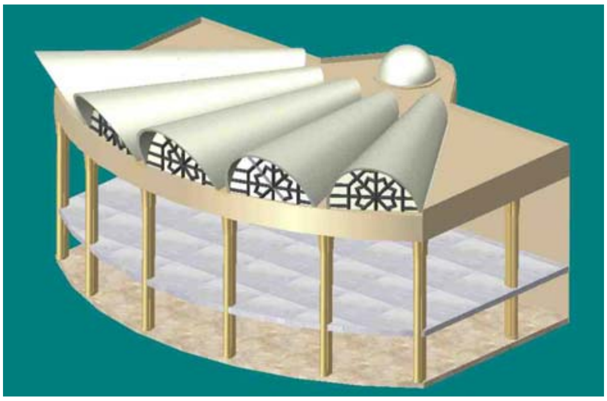

**Figure 2- Architect's Concept Transformed into 3-D Model**

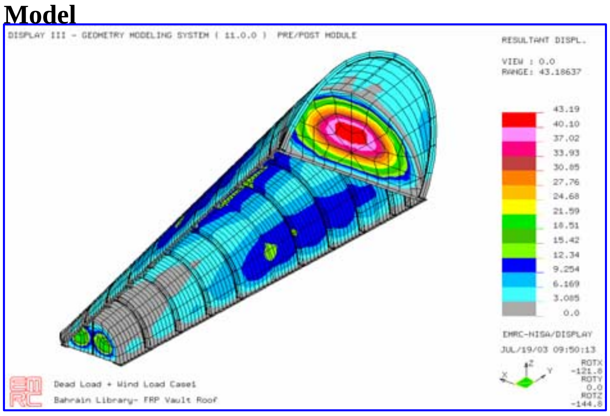


**Figure 3 (a) - Analysis Results - Displacements**

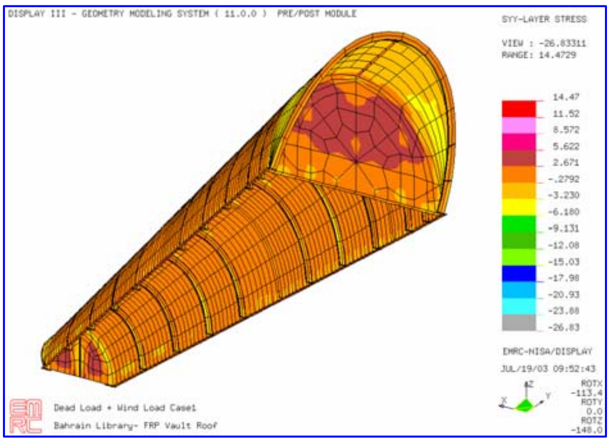


**Figure 3 (b) - Analysis Results - Stresses**

**Figure 4a- Mould under Construction Stage 1**

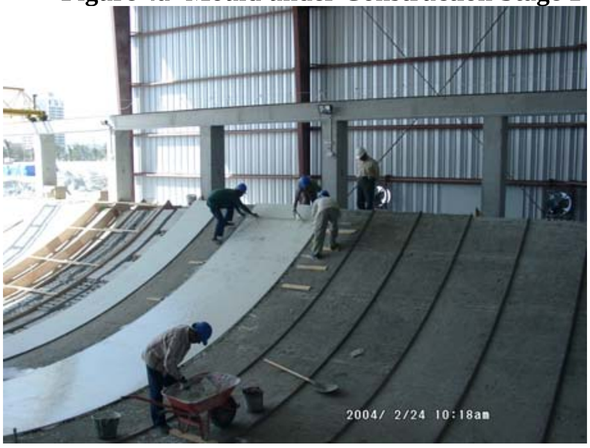


**Figure 4b- Mould under Construction Stage 2**

**Figure 5 (a) - Manufacturing by Open Contact Mould Technique**

**Figure 5 (b)- Jigs for demolding and handling.**

**Figure 6- Gantry Crane and Demolding Jig**

**Figure 7(a) Panels on the Assembly Jig**

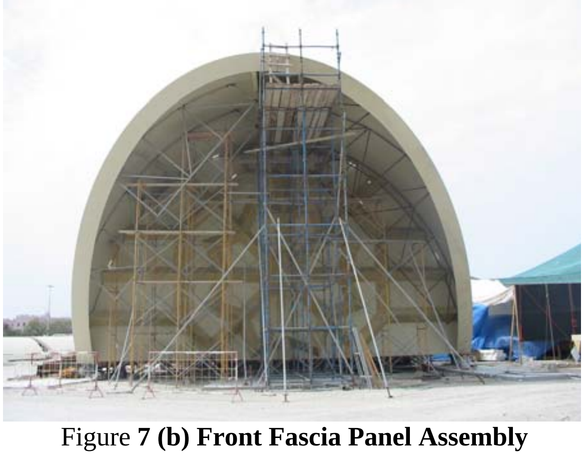

Figure **7 (b) Front Fascia Panel Assembly**

**Figure 7 (c) Ridge Flange Bolting**

**Figure 8 (a) – Central Section lifting on jig**

**Figure 8 (b) – Front Section lifting on jig**

**Figure 8 (c) – Front & Central section alignment**

**Figure 8 (d) –Installation at Final Position**

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