DESIGN AND CONSTRUTION OF A ELLIPSOIDAL COMPOSITE SHELL COVERING A METALLIC GEODESICAL STRUCTURE

A. Marmo[1*], F.J.X. Carvalho[1], Guido Damilano[2] Freire Gabriel[3]
B. [1]IBCom, Taubaté, Brasil, [2] IAE-CTA SJCampos, Brasil [3]SEAOIL, Rio de Janeiro, Brasil
* Corresponding author (amarmo@terra.com.br)

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1 Abstract

This paper describes the structural analysis and construction of a ellipsoidal composite shell. Fig1
The structural thin shell was modeled with 3 and 4noded shell elements using effective engineering properties derived from a micromechanics theory.
The Shell construction and assembling was based in the metallic structure project and the shell was designed divided in segments of about 16 m^2.
The methods and dimensioning of those segments is described as well as the assembling and determination of fixing points.
The laminate construction, formulation and properties are described.
Special auxiliary devices for hand lay up of large parts were developed.
The shell elements were fixed in pivots placed at some of the nodes of supporting metallic structure.
Corrections due to unexpected deformations in the metallic structure were determined by laser measurement, method that uses laser scanner/point cloud to generate the CAD model of the real structure with a precision of 1mm .

Fig1 ellipsoidal composite shell

Introduction

The moldability of GRP composites makes this material suitable for complexes geometry building application, in this case, a ellipsoidal shell 14 m high with axis 36 m and 26m long, supported by a geodesic metallic structure.

The load considered for design was 100kgf/m^2 as resultant of all actuating loads over the shell.

For construction facility, the complete shell was divided in several segments of about 16 m^2 having each one a defined position in the final assembling.

The composite parts were constituted of intercalated layers of chopped glass fiber mats and woven glass fiber roving with a special low smoke polyester resin that complies with the safety standards regulation for building application.

The parts were molded by hand lay up with some auxiliary devices facilitating the laminating of large parts.

Results of the finite element analysis of laminated composite thin shell structures are presented in the study. There is no need to discuss the importance of shell structures. Their efficient load—carrying capabilities have rendered their use widespread in a variety of engineering applications The continuous development of new structural materials leads to ever increasingly complex structural designs that require careful analysis.

Although analytical techniques are very important, the use of numerical methods to solve shell mathematical models of complex structures has become an essential ingredient in the design process. The finite element method has been the fundamental numerical procedure for the analysis of shells. The research activity in the area of finite elements for plate and shell structures spans a period of over three decades and continues to be very intense.

An important consideration discussed in is that shell finite elements are nowadays being integrated in CAD (Computer Aided Design) systems, exposing design engineers that are relatively inexperienced with the details of shell element technology to the use of such elements.

Lamina and laminate characterization

The laminate composition was: Intercalated layers of glass fiber chopped mats and woven roving fabric.

The fiber weight fraction is 35%

The resin was…………charged 50% in weight with hydrated alumina.

Total laminate thickness: 5.08 mm

Fiber glass volume fraction: 23. 9 %

Matrix resin plus alumina density: 1.51 g/cm^3

Laminate density: 1.77 g/cm^3

The polyester resin …….. charged with 50% of hydrated alumina complies with fire and low smoke emission regulations determinate by building authorities.

Laminate Matrix A

$$A := \begin{bmatrix} 75088 & 22527 & 0 \\ 22527 & 75088 & 0 \\ 0 & 0 & 14868 \end{bmatrix}$$

$$A^{-1} = \begin{bmatrix} \frac{75088}{5130742015} & -\frac{22527}{5130742015} & 0 \\ -\frac{22527}{5130742015} & \frac{75088}{5130742015} & 0 \\ 0 & 0 & \frac{1}{14868} \end{bmatrix}$$

Modulus

E1=E2=68329.72kgf/cm^2

Ultimate shear stress = 1.73 Mpa

Total load to be absorbed by the shell 100 kgf/m^2 (surcharge)

Results of the FEA

The success of this model (3- and 4-noded shell elements with **2x2x2** reduced integration), in accurately predicting the structural behavior of the shell under simulated loading conditions, has led to FEA studies to determine the sensitivities of the shell's structural performance to material property distribution which arise from the variation in parameters, such as moduli of the constituents, fiber volume fraction, and ply arrangement of the laminates.

The σ_{11} and σ_{13} stresses distributions are due a maximum pressure of 1.0 kPa. The σ_{11} stresses, which are related mainly to the flexural behavior of the shell, are high at the sections along the major and minor axes of the elliptical shell where high bending moments, created by the external pressure, are experienced. The maximum $\square_{11}$ stress is equal to **0.32 MPa** (fig2)in compression for the inner fibers at the major axis section. The maximum shear stress σ_{13} is 1.73 MPa, which occurs at the neutral axis locations of the cross sections at the transition area of the shell where insert supports discontinuity is present.

The longitudinal (ε_{11}**)**, transverse (ε_{22}), and through-thickness shear (ε_{13}) strain distributions due to the maximum pressure of 1.0 kPa for the model are described as follows. The longitudinal (ε_{11}) strain distribution at the cross section of the shell essentially results from the combined effects of the flexural deformation caused by the pressure loading, and the stretching created by the stack load. The transverse (ε_{22}) strain distribution is mainly determined by the Poisson's effect of the distribution is similar in trend, but lesser in magnitude. Note that a Poisson's ratio of 0.3 was used for the adopted material. Finally, a stress analysis cannot be concluded without mentioning the issue of failure. The failure criteria adopted was the : Maximum Stress Failure**.**

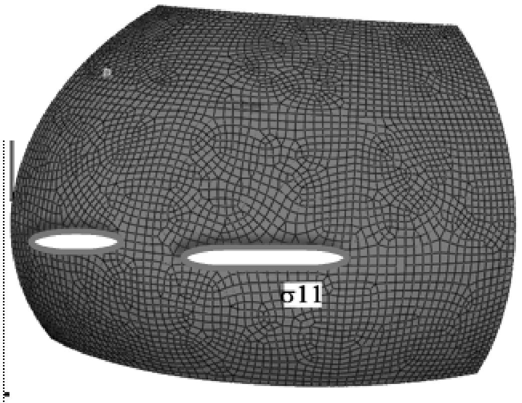

Fig2 σ_{11}max

Stress fields are much more complexes in composites, which can delaminate or have either fiber or matrix failure. The problems in defining failure modes for the composite shell and the Issue of what constitutes a proper failure criterion in predicting reasonable fatigue life for the shell must be addressed in future work.

Composite Shell fabrication

The shell was divided in parts according to ellipsoid regions; moulds of different shape and size were produced. The parts were laminated in a provisory industrial hangar not far from the construction site and the lamination process was hand lay up.

As the parts were large, a special laminating device was developed , consisting of a laminating roll with a long arm coupled to a resin dispenser. The resin already mixed with alumina is picked by a metering pump, and the catalyst is dosed proportionally to the resin flow before dispensing in the roll.

After cured parts are trimmed and kept in a social support to avoid deformation.

Assembling

Parts are supported over composite skids placed at each metallic structure node, as shown at **fig 4**

Fig 4a External

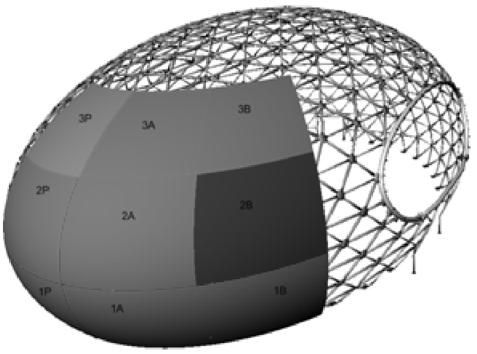

Fig 4a External

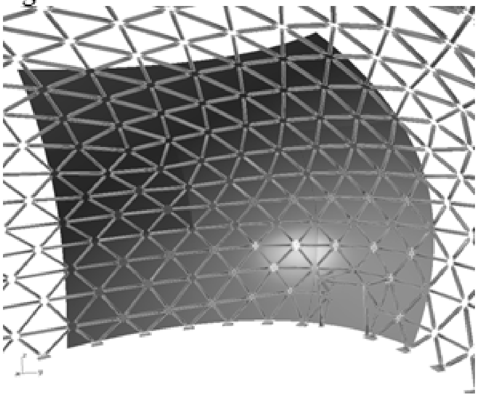

Figure 4 b Internal

The parts junction was filled with a elastomeric adhesive filled with glass microspheres having a elongation compatible with maximum allowed shell displacement.

The shell structural design was based in the condition that the maximum metallic structure displacement should not be greater than 12 mm, otherwise the perfect assembling would not be possible.

The shell design was based on the metallic structure 3D CAD, with an offset of 50mm to accommodate any minor defects. Before starting the shell assembling, measurements were made using laser measurement method that uses laser scanner/point cloud to generate a CAD model of the real structure with a precision of 1mm.

The generated model was overlaid on the theoretical model in a CAD environment, using the concrete base as reference. This overlaid model made possible to map the real deformations of the metallic structure, evidencing that in some regions deformations have exceeded the maximum allowed by the project. This model also helped the generation of a Correction Plan, making possible to correct the metallic structure just on the points where it was above the tolerance.

Once these critical points were corrected, a new measurement was made to confirm that the structure was complying with tolerances.

Based on this new measurement the exact size and location of each of the shell supports were calculated according the the real position of the metal structure, allowing shell to assume the designed geodesic shape.

References

[1] A. Green, B. Red and C. Blue "*The title of the book*". 1st edition, Publisher, 2001.

[2] A. Green, B. Red and C. Blue "The title of the conference paper". *Proceedings of Conference Title*, where it took place, Vol. 1, paper number, pp 1-11, 2004.

[3] A. Green, B. Red and C. Blue "The title of the journal paper". *Journal Name*, Vol. 1, No. 1, pp 1-11, 2006.