Design of 328 Meter Diameter Double Layer Spherical Dome

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ABSTRACT

The design of a 328 meter diameter aluminum dome with a new double layer structural system is presented. Numerical methods are used to analyze the dome structural behavior under environmental loads and to evaluate critical buckling loads.

INTRODUCTION

Aluminum domes are being increasingly used for clear span architectural applications. The advantages of aluminum are numerous and include its corrosion resistance, light weight, manufacturability, and high strength to weight ratio. The limits of clear span aluminum construction have yet to be reached as the largest architectural aluminum dome built to date is the 126 meter dome covering the Spruce Goose in Long Beach, California (Lopez, 1996). This paper explores the limits of clear span aluminum construction by presenting the design of a dome with a lower profile and of a diameter almost three times as large as the prior referenced Spruce Goose dome.

DESCRIPTION OF THE DOME STRUCTURE AND STRUCTURAL SYSTEM

The 328 meter dome is spherical in shape with a rise of 66 meters. The dome structure is supported at 192 locations and consists of a double layer triangulated lattice framework. The outer layer is fully triangulated and is composed of 25,408 wide flange beam elements interconnected at 5,728 joints. The inner layer consists of a hexagonal grid formed by 8768 wide flange beam elements interconnected at 5,792 joints. A total of 16,784 diagonal pipe members rigidly connect the two layers which are separated 2.44 meters. A scaled model of the structural system is presented in Figure 1. Figure 2 shows a section of the outer dome layer and the corresponding section of the inner dome layer and interconnecting pipes.

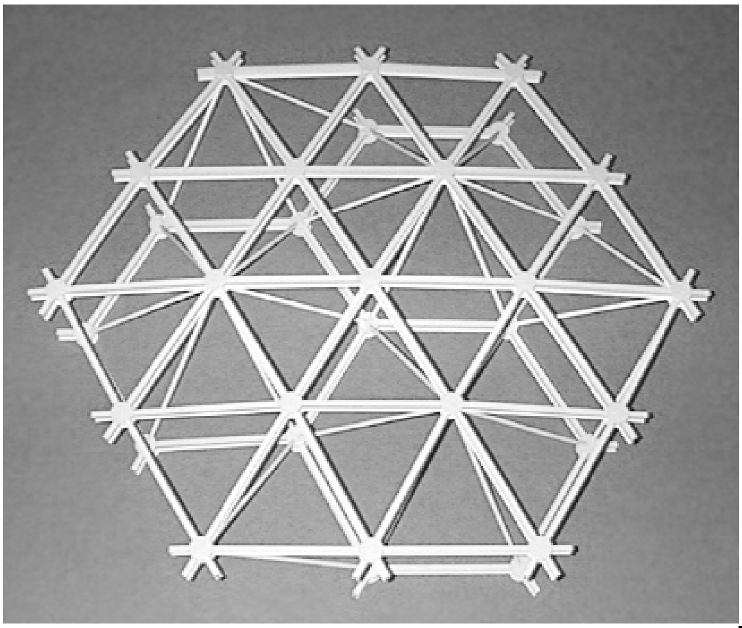

Figure 1. Structural system model

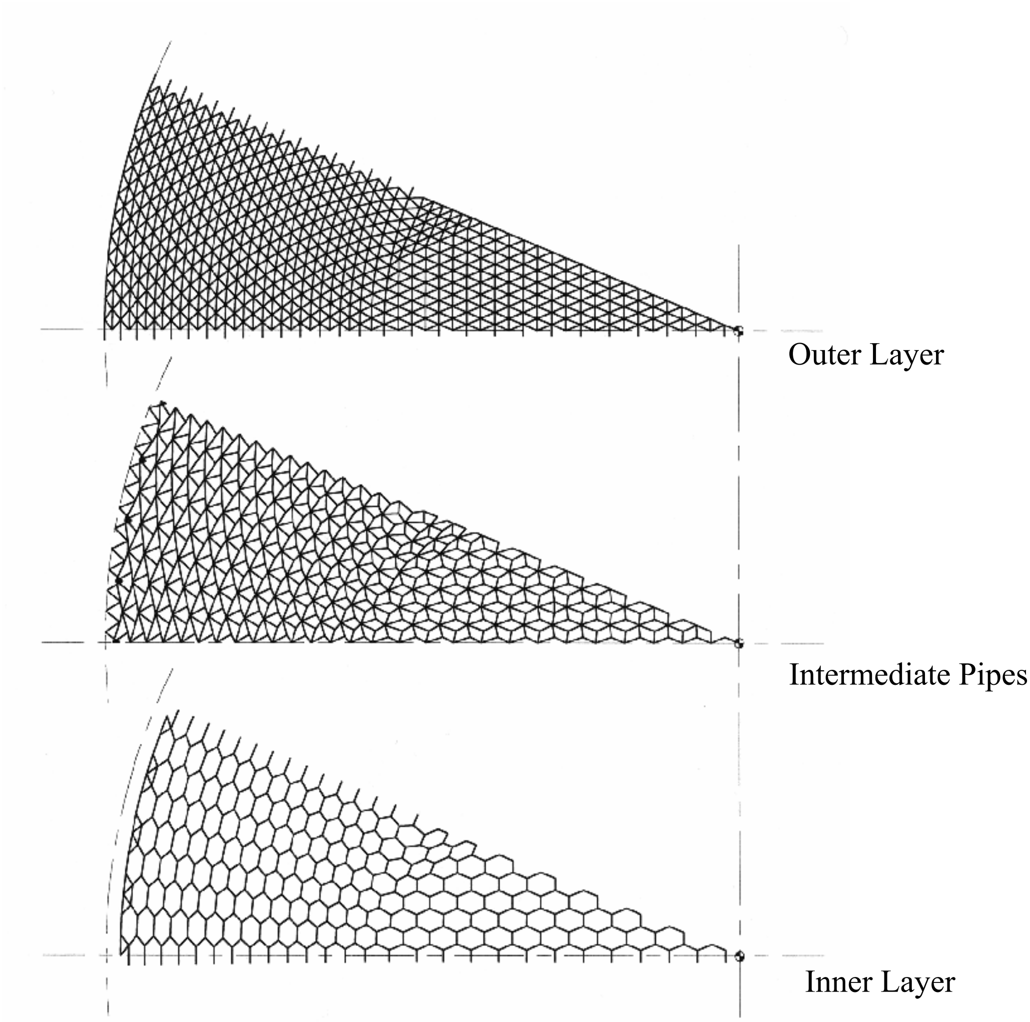

Figure 2. 22.5° sector of dome.

The structural system is covered by an integral interlocking panel/batten system. The triangular panel membranes are connected to the upper layer structural elements as shown in Figure 3. The panels are of particular importance to the structural response. While they have no bending stiffness, they stabilize the top flange of the outer layer structural beam elements against lateral deflection. This increases the member buckling strength by forcing individual members into a different failure mode. The beam elements at both the outer and inner layers are connected with top and bottom gussets to ensure high axial load and moment transfer within the layers. The dome is designed for a uniform live load of 0.72 kN/m^2. The total design live load is 60,800 kN. The inner layer members have a depth of 20 cm and the outer layer members have a depth of 25 cm. The average cross sectional area of the members in both the inner and outer layer is 40 cm^2. The diagonal pipes have an area of 20 cm^2 and an outside diameter of 11.5 cm.

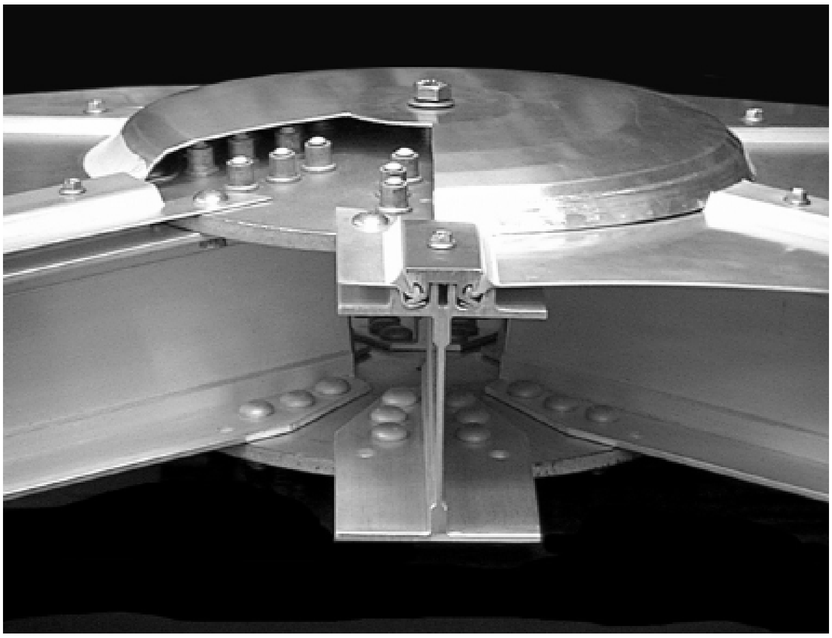

Figure 3. Panel joint connection detail.

STRUCTURAL BEHAVIOR AND STABILITY ANALYSIS

The behavior of the double layer dome structure presented in this paper is similar to the response of a system that consists of two concentric thin shell surfaces rigidly interconnected to maintain constant distance during loading. In this sandwich like structure, external forces are transformed into axial forces that travel primarily along the inner and outer layers of the dome. The diagonal pipes that connect the inner and outer layers carry very little load and are primarily designed to maintain the two layers separated at a constant distance. The average axial force of the upper layer members is 250 kN; the average axial load of the inner layer members is 170 kN; and the average axial load of the diagonal pipes is 40 kN.

The dome structure is supported at 192 perimeter joints, all of which are part of the outer layer. The support configuration chosen forces the loads to migrate from the lower layer to the upper layer in the vicinity of the perimeter supports thereby increasing the axial load in the diagonal members in this area.

The modified Riks method is used to track the load-deflection behavior of the structure. The incremental load-deflection analysis is performed by applying uniformly distributed loads on the dome outer layer. The modified Riks method follows the equilibrium path up to the bifurcation point. Figure 4 shows the vertical deflection at the node with maximum deflection as a function of the total applied load. The load deflection curve shows the nonlinear unstiffening behavior of the structure before the ultimate buckling load is reached. The corresponding failure mode is shown in Figure 5. For clarity, only the outer layer beam elements are shown in the mode deformation plot.

The total applied load to the structure at the onset of buckling is 190,000 kN which corresponds to 2.2 times the design load. The structure is therefore capable of supporting the design load without failure and 2.2 represents the design safety factor.

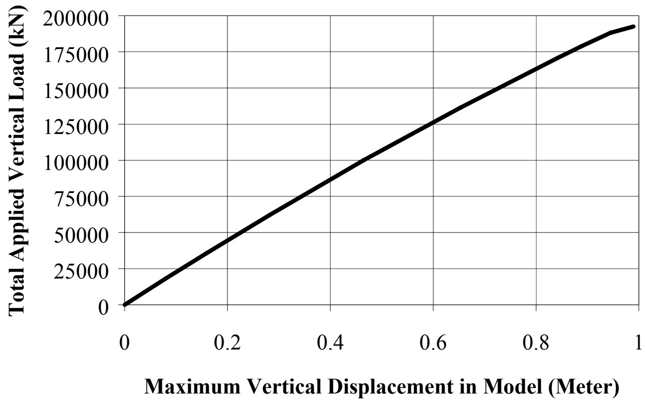

Figure 4.

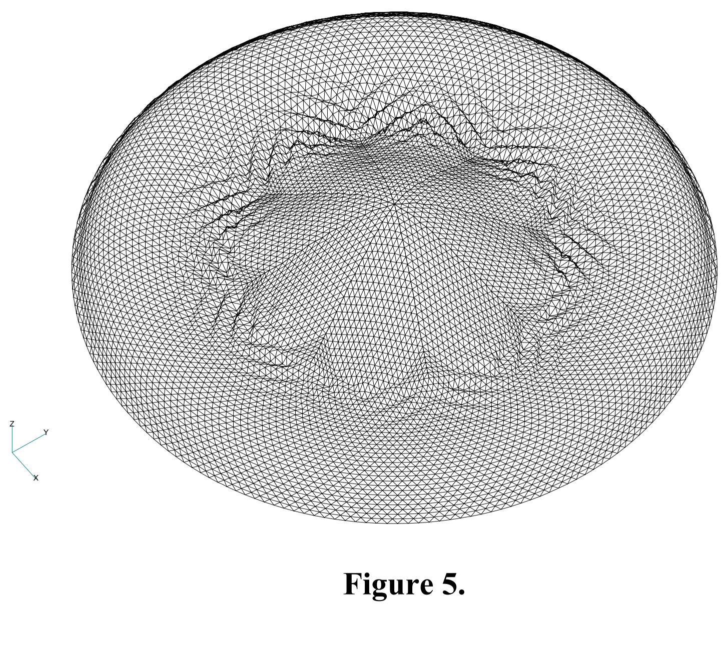

Figure 5.

CONCLUSIONS

The design presented confirms that double layer aluminum structures can be used for clear span applications well over 320 meters. The strength of the structural system presented is due primarily to the large distance between layers and the curvature of the dome surface. The structure is stable under the design loads considered. If required, for loads larger than those presented in this design or for different load distributions, the structure can be stiffened by completing the triangulation of the inner layer and/or increasing the cross sectional properties of the top and bottom structural elements.

REFERENCE

1. Lopez, A.; Troup, K. "Aluminum Lattice Structures: Developments and Innovations in Clear Span Roof Solutions", presented and published at the IASS International Symposium on Conceptual Design of Structures, October, 1996, Stuttgart, Germany.