The First Rigidly Clad "Tensegrity" Type Dome, The Crown Coliseum, Fayetteville, North Carolina

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Abstract

This paper presents the first known "Tensegrity" type, Cabledome, structure with rigid roof built for the Crown Coliseum, Fayetteville, North Carolina, USA, a 13,000 seat athletic venue. Recently completed by the authors, the structure clear spans 99.70 m (327 ft.) employing a conventional rigid secondary structure of joists and metal deck. The structural design addresses cladding of the relatively flexible primary dome structure with rigid panels. The design combines the advantages of the Cabledome system with conventional construction. This project demonstrates the utility of tensegrity type domes in structures where tensile membrane roofs may not be appropriate or economical.

The authors discuss the behavior, the unique design and the realization of this structure.

1. Introduction

A number of long span "Tensegrity" dome type structures have been realized in the previous decade pursuant to the inventions of R. Buckminster Fuller (Fuller) and David H. Geiger (Geiger). These structures have demonstrated structural efficiency in many long-span roof applications. While these domes can be covered with a variety of roof systems, all the tensegrity domes built to date have been clad with tensioned membranes. As a consequence of the sparseness of the Cabledome network, these structures are less than determinate in classical linear terms and have a number of independent mechanisms or inextensional modes of deformation (Pelegrino). In these modes load is primarily resisted by changes in geometry of the tensile network. The relative flexibility of these structures to asymmetric loading has made the use of tensile membranes for the roof a logical choice.

In 1984 David Geiger developed the idea of the “Cabledome”. It was conceived to be used with a tensile membrane roof cover. In fact, his development of the design was initiated by the desire for a tensile membrane structural system with its positive attributes but without the vulnerability of the large span air-supported roofs. A number of Cabledomes and Fuller domes (Campbell, 1994) have been built in this manner. Starting with two venues for the 1986 Olympics in Seoul, Korea (Geiger, 1986) (Rastofer), the Redbird Arena in 1988, USA (the first oval cable dome), the Florida

Suncoast Dome, USA (Geiger, 1988); the Georgia Dome, USA (Levy, M.); and the Tayouan Arena, Republic of China, all these domes use a tensile membrane for covering.

Daylighting through the translucent roof membrane has always been a positive attribute of these structures in athletic venue applications. However such translucency in multipurpose sports and entertainment venues is undesirable as entertainment productions prefer to have complete theatrical control of light inside the venue. (Campbell, 1992)

2. The Concept

In 1994 the Convention Authority of Cumberland County North Carolina, USA, decided to build a 13,000 seat venue as an addition to its exhibit complex in the City of Fayetteville. The Project Architects, Odell Associates Inc. of Charlotte, NC., developed a facility with a circular seating plan. A number of roof structures which exploited this circular geometry were developed and compared before the Cabledome scheme was selected as offering the best combination of economy and architectural features. The opaque roof combined with the favorable economics of employing conventional construction materials and techniques made the choice of the rigid secondary structure appropriate. The overall diameter of the arena seating bowl and thus the roof is 99.7 meters. (327 ft) The roof has three tension hoops. The roof is segmented radially into 18 pie shaped sections. See Figure 1.

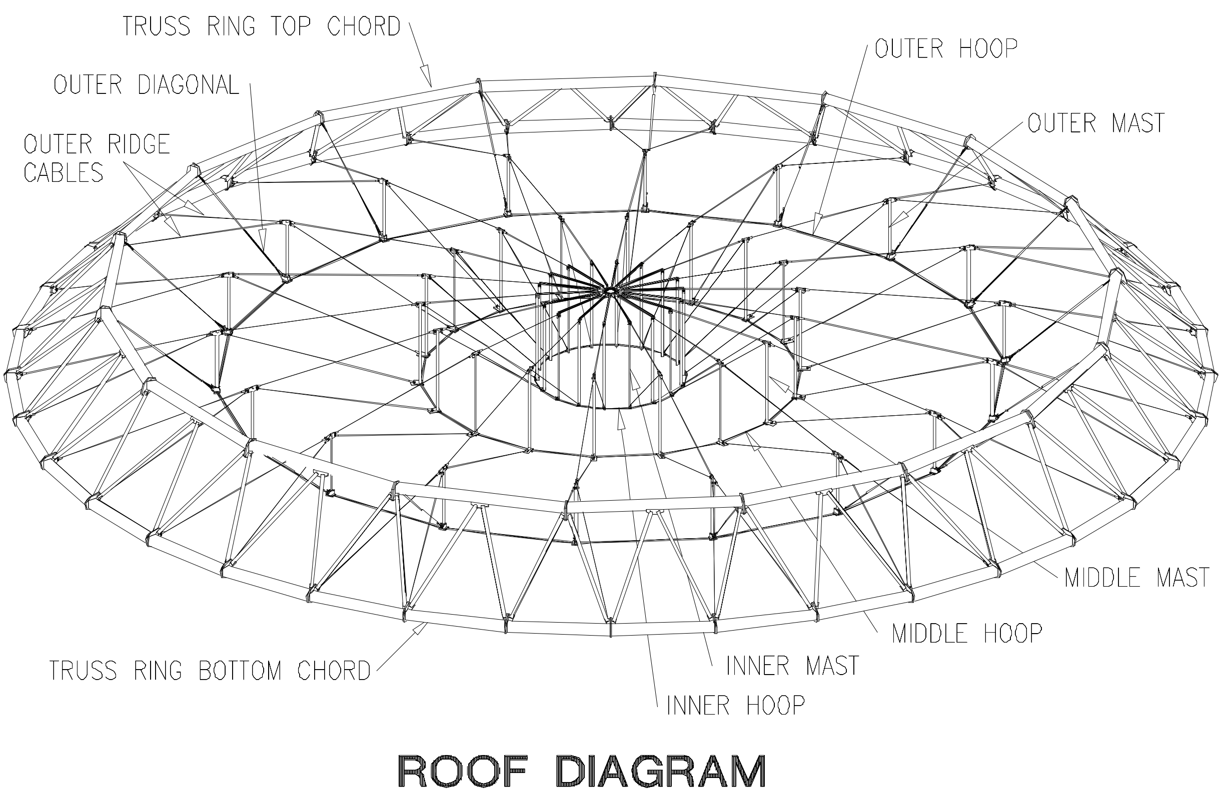

Figure 1

The Cabledome system is intentionally "underdeterminate" in order to exploit geometric redistribution of nonunifrom loads. (Campbell, 1994) The arrangement of typical Cabledome cable/strut network was somewhat modified in this design. The perimeter compression ring is a conical truss. The top chord of the truss ring anchors the diagonals; the bottom chord the ridge cables. The roof panels follow the surface created by the ridge cables. The outer diagonals pass through the roof surface to be anchored to the top chord of the ring truss. The outer most link in the ridge cable was splayed from the top of the mast to the bottom chord of the compression truss ring so as to allow the ridge cables and the outer diagonals to terminate at a panel points on the ring truss. The general arrangement is shown in Figures 1, 2 and 3. The ring truss is completely exposed and the roof surfaces held away to enhance the architectural impact of this element. This configuration gives the ring truss the appearance of a crown.

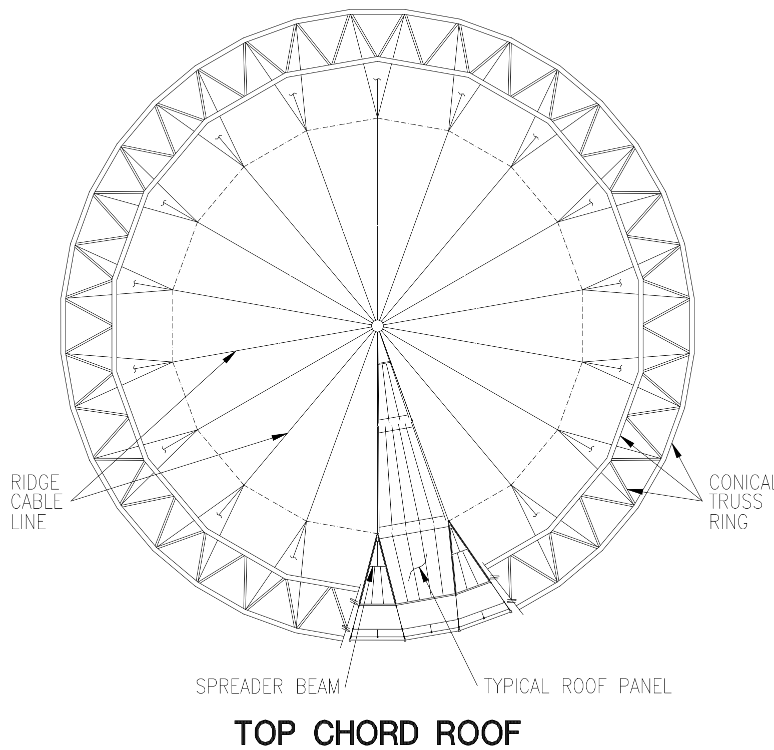

Figure 2

The rigid secondary roof structure consisting of metal deck, open webbed bar joists and steel girders was assembled into panels. These are supported directly on the cable/strut network. The marriage of a flexible Cabledome system with a rigid decking system was achieved by designing the roof cladding as panels which "float" in the cable/strut network. The authors have previous experience with rigid roof panels on flexible roof structures (Geiger, 1977). The corners of the roof panels coincide with the masts of the Cabledome. The panels are supported only at these points. Thus the load is introduced into the Cabledome network at its "hard points".

Each panel has four support points. Relative deflection between masts does not cause significant forces in the panels due to their very low warping stiffness. The joints between panels follow the change of slope dictated by the cable net. Radial and circumferential joints between panels are released to allow for the rotation between panels as they follow the distortion of the cable/strut network. The panels' radial joints are expansion joints, to preclude development of hoop forces in the roof panels.

The support details for the panels are such that the gap between the center of the ridge cable and the roof panel is kept to a maximum of 76 mm (3"). This was done to reduce the movement between panel borders resulting from their rotation about the cable axis. In the radial direction bellow type expansion joints were incorporated into the roofing at the change of the circumferential slope, which falls along the ridge cable lines. This detail allows for rotation as well as circumferential movements. The circumferential joint is accommodated by leaving the roofing membrane unfastened for a 610 mm (24 ") wide strip over the panel joint. This detail eliminates any barrier to the run of rainwater.

3. Analysis

As the roof panels were designed to be non-interactive with the primary supporting structure, only the cable/strut network and the peripheral truss were modeled for analysis. The roof structure was analyzed by computer employing Geiger Engineers' in house program based on perturbation theory (Levy, R., 1995) which employs an iterative analysis procedure to account for the geometrically non-linear behavior of the system. The load was determined by a system of consecutive steps using the final configuration of the structure for a given step as the initial approximation for the following one. Within each load step the geometrically non-linear analysis was reduced to an application of the Newton's method to equations describing perturbed conditions with an approximation of the stiffness matrix by combining the elastic and geometric stiffness matrix. The quantitative analysis of such combined system matrix allows detection of system instabilities. The structure was analyzed for prestress of the cable net, vertical and lateral loads as well as unbalanced loads due to show rigging. The show rigging load used was 534 kN (120,000 lbs).

During the analysis of the initial network a system instability was detected. Conventional analytical means of prediction of system instabilities are useless for this class of structures as a consequence of their non-linear behavior and reliance upon geometric stiffness. Instabilities within the loading conditions analyzed will be predicted by the analysis. To assure stability of the structure for load condition in excess of service loads, the structure needs to be analyzed for those loads. (Hamilton)

In the Cabledome the masts are supported at their base by diagonal cables. The horizontal component of the diagonal at the mast is resisted by a circumferential tension hoop. The top of the mast is held by radial cables. All cables are under tension. Even though the mast at the top is laterally held in only one plane, the radial arrangement of the ridge cable exerts a self stabilizing force against any out of plane movement.

The instability encountered in preliminary design occurred at the bottom of the outer mast. In designs of other Cabledomes this particular instability did not occur.

Investigation determined its cause due to the fact the ends of outer diagonals were located above the top elevation of the outer struts. This allowed for a system instability mode where the entire outer hoop rotated in plan. This was rectified in the design by attaching the splayed ridge cables laterally to the diagonal cable at their intersection in the radial projection with a small spreader beam. (This connection provided other design benefits as it forces compatibility of movements of the diagonal and ridge cables in the plane created by the splayed ridge cables. Since this is in the plane of the roof surface, relative movement between the intersecting diagonal with the roof would otherwise require an elaborate flashing detail.) See Figure 3.

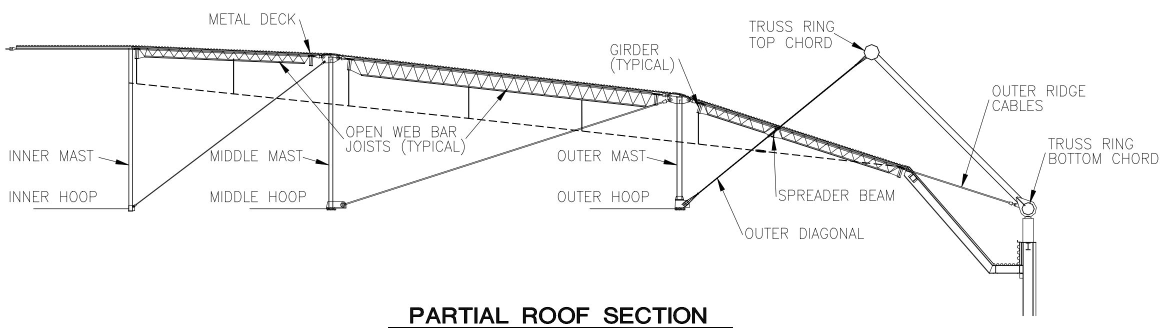

Figure 3

4. Construction Details And Erection

The construction of the roof followed the erection of previous Cabledome structures (Tuchman). After the erection of the support structure the peripheral ring truss was erected. It is composed of spiral welded pipes of 1016 mm (40") diameter for the cords and of 305 mm (12") diameter for the diagonals. Thickness of the pipe varies from 12 to 16 mm (1/2" to 5/8") At the mitered joints the pipes are butted and bolted together through perimeter flange plates. These plates also accommodate a true pin connection to the supporting columns. Thus the roof is pinned all around to its supports. The columns are flexible at their base in the radial direction. This allows for the release of thermal movements of the roof and specifically the exposed ring truss. Lateral stability is obtained by four braces in the circumferential plane in-between the columns. Adjacent braces are oriented 90 degrees to each other.

The tension elements of the cable/strut network are assembled from structural strands except for the outer most diagonals, where seven wire prestressing strands are used. The struts consist of 260 mm (10 inch nominal) diameter steel pipes. After the whole cable/strut network was assembled on the ground, it was jacked into place from the compression ring by temporary diagonals. These were replaced with the final tendon bundles just before the final prestress was to be introduced into the system. Temporary guys to the bowl structure at two locations stabilized the system against the instability discussed above. These were removed after the spreader beams, which attached the outer diagonals, were installed.

After pre-tensioning of the Cabledome network the roof panels were installed. Figure 4 is a construction photograph taken prior to this stage, showing the roof panels assembled on the ground. (Roof panels at the right of the photo). Pie and trapezoid shaped panels were pre-assembled on the ground consisting of bar joists and metal roof deck and lifted into place. Insulation and a roofing membrane were installed in place after erection of the panels.

Figure 4

The behavior of the roof is as expected. Heavy loads such as a scoreboard, catwalks and other equipment are permanently suspended from the structure. Concert productions with random hanging loads of up to the 534 kN have been rigged from the structure resulting in a maximum deflection of 228mm (9") without difficulty.

We believe that this system is a cost effective solution to covering large spans, due to its few components, conventional construction, and fast erection.

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