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FABRIC FORMS FOR STEEL AND FEROCEMENT ROOFS

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Abstract

The intent of this paper is to document the fabric forms for steel and ferrocement roofs that can be employed for small 15x15 feet and large span (100x100feet) roof systems in India/World. This paper will discuss the engineering design methodology and structural analysis & design for a small steel roof (Hyper fabric form). This includes how the steel shell form is generated by fabric form finding software program Mathform, a software program based on the dynamic relaxatation method, and the process of fabricating profiled laser-cut and bent steel sheet-metal roof cover. Another proposed project, a ferrocement roof cover for a large amphitheater in an institution building in Bijapur, India is also discussed. This roof consists of three eccentric shells, each of approximately 60feetx60feet span and approximately 20 feet high. The roof shell form is generated by fabric form-finding software program Mathform, and is proposed to be built on site with a structural frame of angles and rods (tubes) with a proposed proprietary method of assembled and welded elements supporting a ferrocement roof cover.

Keywords: Form-finding, Fabric forms for steel roofs and Ferrocement roofs

1. Introduction

Fabric-form structures are one of the most exciting and developed technologies in roof cover today. Conceivably the most exciting aspects of fabric forms are the remarkable diversity of anticlastic forms that can be realized. These include hyperbolic shapes, saddles, cones, domes, vaults, and waved and plate types. The choices are endless. As their life is limited to 5-20 years due to weathering in wind, rain and sun, these fabric structures are categorized as temporary structures. Fabric structures' limited thermal transmittance or thermal conductance, demands appropriate use in the tropical countries such as India for its varied temporal requirements such as shelters for personal transportation or during events like Kumbh mela.

To enhance life span and thermal performance of these structures, fabric forms of steel and ferrocement roofs are proposed. Fabric forms of steel and ferrocement roofs have advantage of a remarkable variety of anticlastic fabric forms and improved thermal performance.

2. Design of fabric forms for a prototype steel roof.

The fabric forms for steel and ferrocement roofs are improvisations of the fabric structure design. i.e., the design phase of the prototype structure is similar to design of fabric structures. The fabric forms for steel and ferrocement roofs are achieved in three steps:

1) Form-finding or Initial geometry formulation
2) Engineering analysis
3) Patterning for steel roofs or cover design.

2.1 Form-finding or Initial geometry formulation:

This is very much a tensile fabric form as the form is derived using a tensioned fabric form-finding software. Form-finding or Initial geometry formulation establishes the detailed geometric description of the final desired shape of the structure.

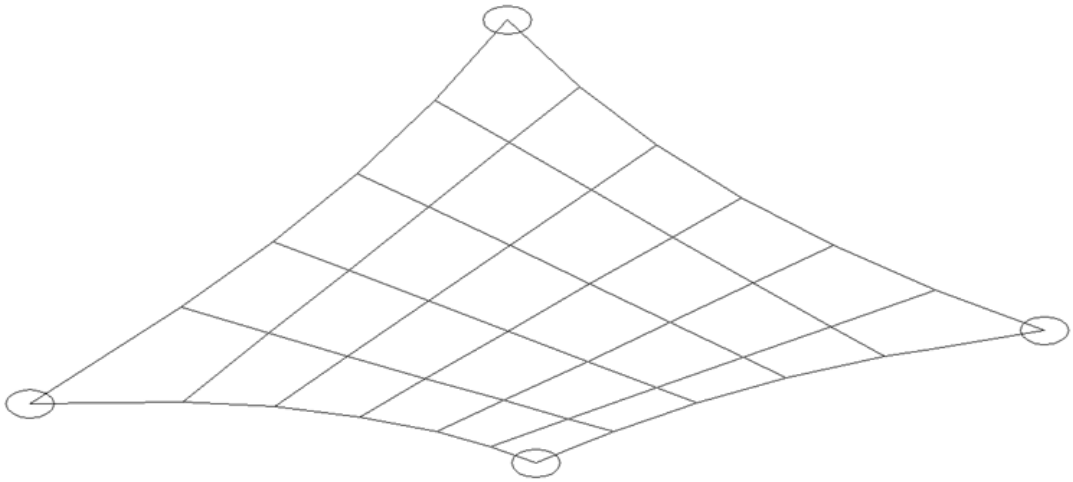

Figure 1: Form finding analysis establishes the shape of the structure

2.2 Engineering analysis.

After form finding, the first step, the structure is analyzed using SPACE-GASS and SAP 2000 finite element computer programs for the three dimensional analysis and design of space frames with geometric nonlinear cable elements. The frame computer model is constructed by definition of nodal coordinates, and connecting truss and beam elements with the appropriate cross-sectional properties between these nodes (usually imported model from form finding analysis). The supports are modeled as fixed connections at supports.

Truss elements are capable of resisting only axial forces. The beam elements transfer moments and shear forces with axial force at connection joints. The design of gravity and wind loads are computed based on IS 875(Part-1-3) and seismic load calculation is based on IS 1893 (Criteria for Earthquake Resistant Design of Structure), The computed design loads are applied at the nodes for the various load cases and the load analysis is carried out for each load combinations as per IS 800. Based on the analysis output, minimum member sizing of the elements is achieved.

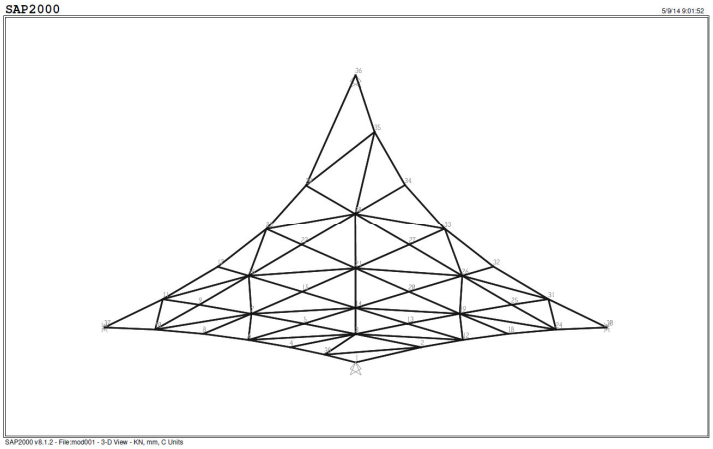

Figure-2:SAP-2000 model

2.3 Patterning for steel roofs or cover design.

Roof patterning is a process of converting a double-curved surface to a flat surface or, mathematically speaking, it is the process of transforming a two-dimensional surface in a three-dimensional coordinate system into a two-dimensional coordinate system with geometrical conformity. Steel roof is essentially a tensile fabric form where the form is derived using tensioned fabric form-finding software.

The form finding model is triangulated and 3D faces are drawn on top of form-found model as shown in the figure 3. This process is called 3D facing. After 3D faceing is complete, strips are selected for flattening (refer to figure 3).

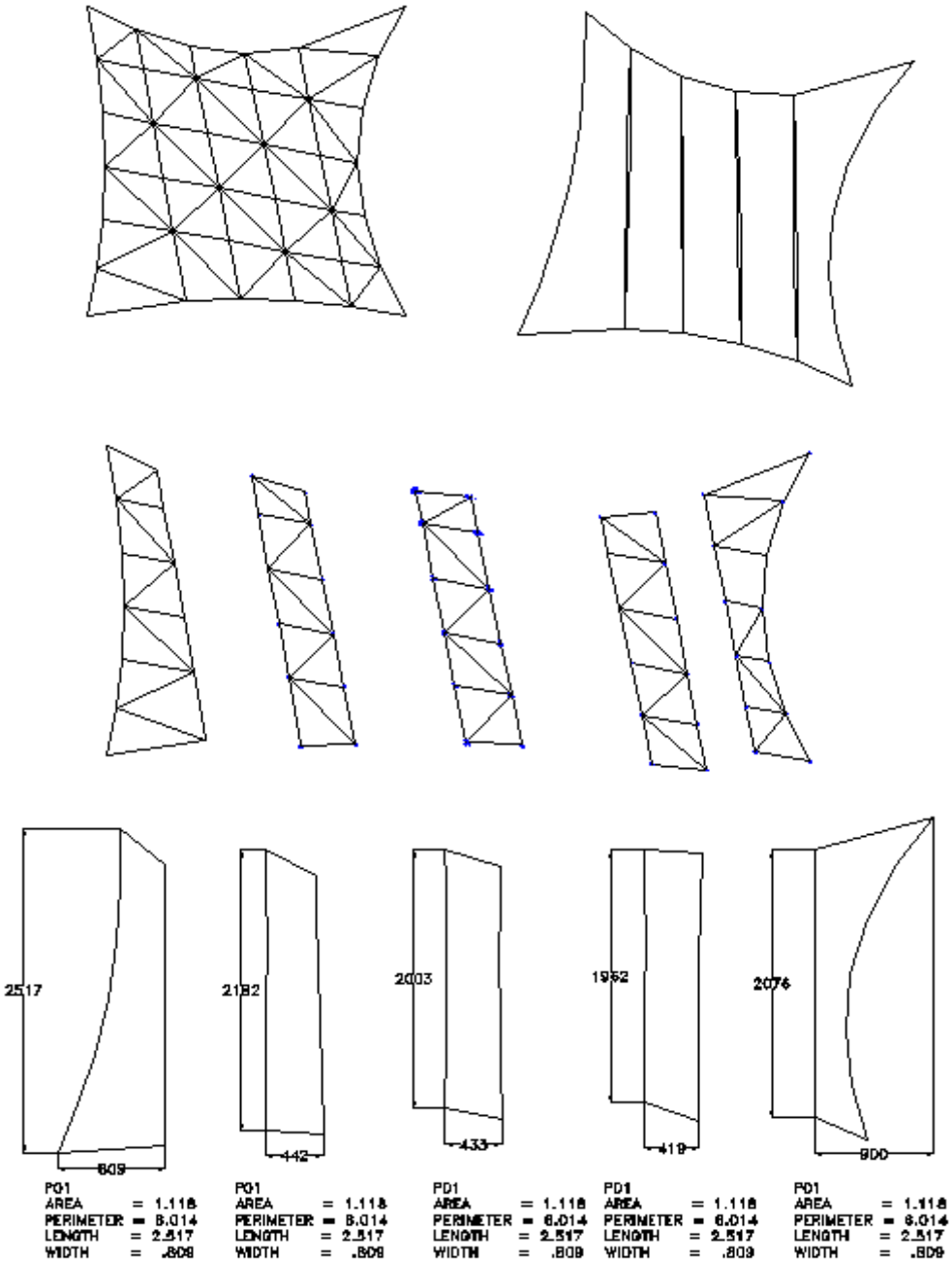

Figure-3: Patterning process

3. Advantages of using fabric for steel roofs:

1) LIFE SPAN: The advantage of steel roof cover is that it is a permanent roof cover (life span of over 50 years) unlike a roof with fabric material.

2) FORMS: The remarkable diversity of anticlastic forms that can be realized. These include hyperbolic shapes, saddles, cones, domes, vaults, and waved and plate types.

3) STANDARDIZATION: Kit-of-parts construction of steel roofs with standardization of members and connections is possible which simplifies erection, provides for fast and better quality construction.

4. Prototype Structure

4.1 Fabrication

This prototype was fabricated using 8mm mild steel rod elements and 50mm mild steel ball nodes. The rod element joining to the ball node angles were identified for node holes drilling and holes were drilled. The node diameter and the node hole depth were used to determine the actual rod element fabrication lengths. Each node and rod element was precision made, labeled and made ready for use in assembly. A typical connection assembly is shown in figure 4. The roof cover is profiled laser cut and bent steel sheet metal.

Figure 4: Small steel roof prototype fabrication & assembly

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4.2 Installation

The fabricated assembly was shipped to site from the workshop, and at site the steel plate cover profile-cut by laser were welded and attached to the frame-work. The roof was lifted and attached to the column support above the ground surface, no scaffolding or shoring was utilized for lifting. Refer to figure4&5 for prototype installation at site.

Figure5: Small steel roof prototype installation

7. Project Application

Fabric forms for ferrocement construction is an emerging technology with the ability to transform ferrocement concrete roofs for permanent roof cover application. To take advantage of this emerging technology we have proposed a fabric form ferrocement roof for a large amphitheater roof cover for an institution building in Bijapur, India. The client aspired for a visible landmark structure with a permanent roof cover to withstand weathering in wind, rain and sun for a minimum period of 50 years. These stringent requirement cannot be achieved with fabric as a roof material, Hence it was proposed build a ferrocement roof cover with structural frame work made from double angles and rods welded/bolted around a custom-designed node, with ferrocement roof cover toping.

The proposed amphitheater structure is an articulated signature building for the existing college campus. The large amphitheater structure with its unique roof accentuates its presence among the nearby buildings. In spirit, the unique shell roof echoes the historic 17th century Gol Gumbud dome in Bijapur Just as the Gol Gumbad expressed the high point of technology of the 17th century, similarly the proposed shell roof will reflect the high point of technology today.

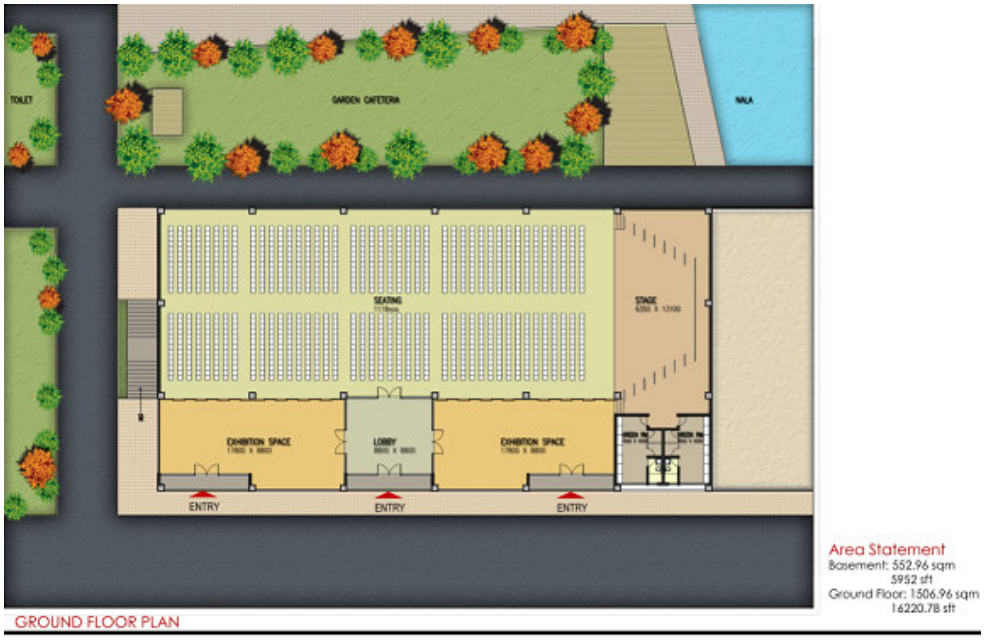

Figure 6. Building typical floor plan

The main structural roof consists of three eccentric shells of about 60feetx60feet each and about 20 feet high. The tops of shells have skylight openings to allow diffused natural sun lighting and ventilation. Entrance lobby is covered with a barrel shell. The roof shell form is generated by fabric form finding software program Mathform, based on the DR method and is proposed to be built with structural frame of angles and rods with a proposed proprietary method of assembled and welded elements on site with ferrocement roof cover.

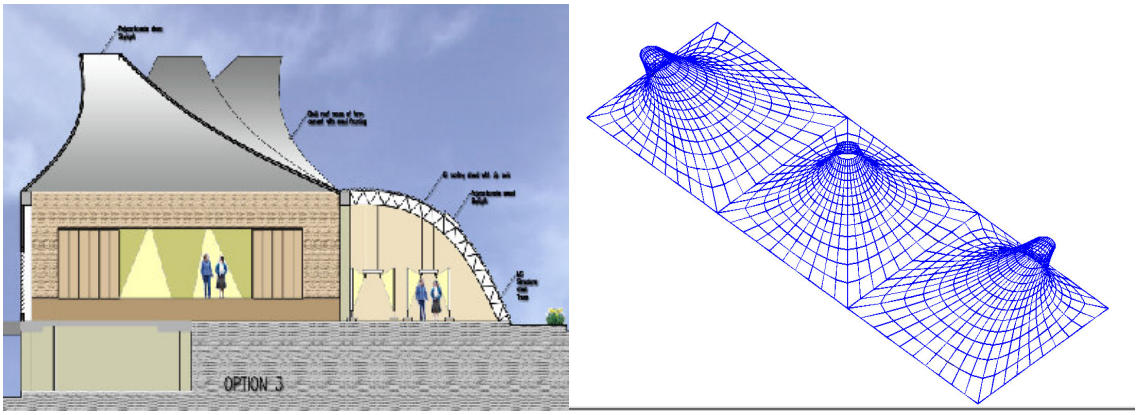

Figure 7. Building typical section and fabric model view

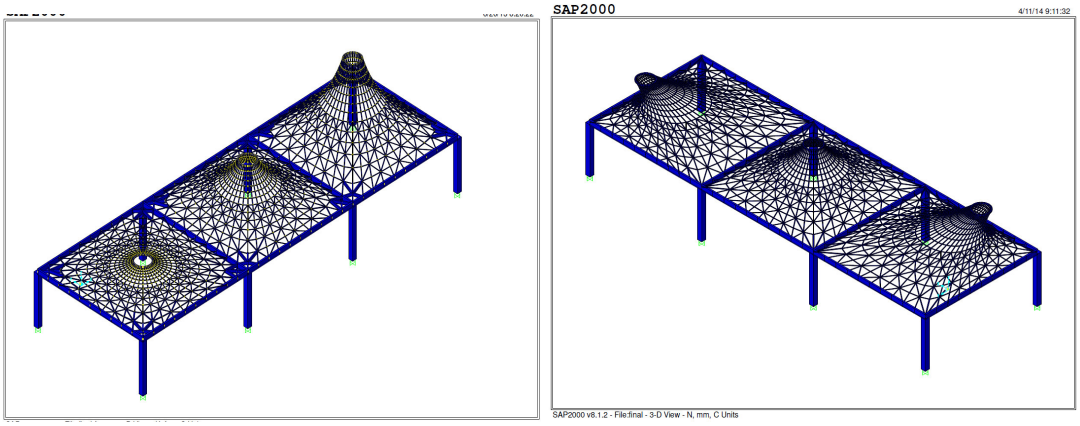

Figure-8:SAP-2000 Structural Frame Model

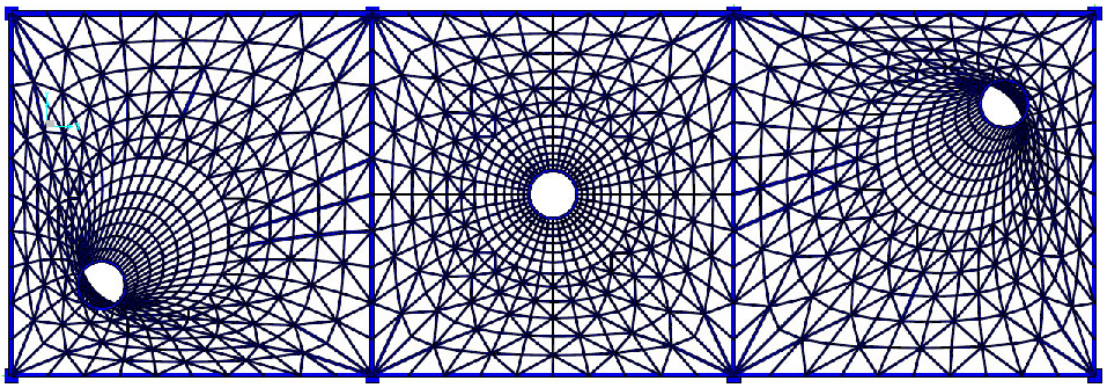

Figure-8:SAP-2000 Structural Frame Model in plan view

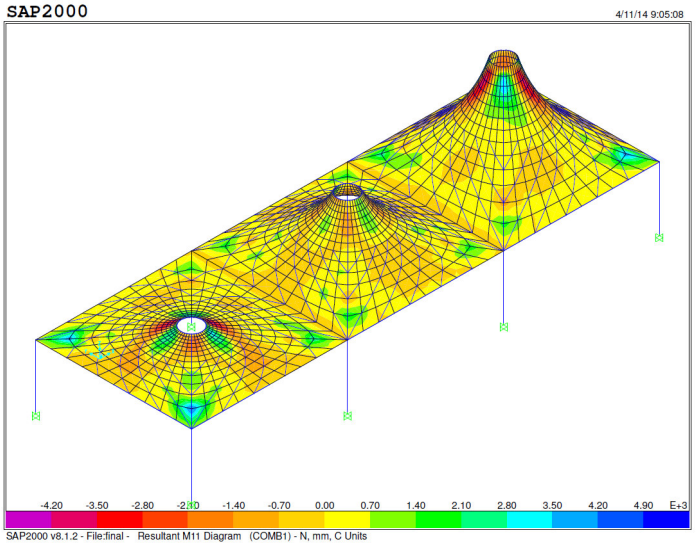

Figure-8:SAP-2000 Structural shell stress plot

7.1 Framing Concepts

The proposed structural system for the new amphitheater is the Reinforced concrete moment frames. Resistance to gravity and lateral forces is provided primarily by peripheral moment frames. The foundations for the structure are isolated concrete spread footings. The roof structure assembly is proposed to be fabricated using mild steel double angle and rod elements and custom steel cast nodes. The double angle and rod element join together through the custom-designed node. Each frame work assembly part, nodes, double angles and rod elements are to be precisely fabricated and labeled for assembly at site. The roof skin proposed is profiled laser cut and bent steel sheet-metal over which a lean concrete with wire reinforcement (ferrocement) is to be placed.

Figure 9. Rendering of the amphitheater structure

Figure 10. Rendering roof view of the amphitheater structure

FINAL REMARKS

Fabric forms for steel and ferrocement roofs is a developing technology in India and around the world. Steel and ferrocement roofs' ability to withstand weathering in wind, rain and sun and to be a permanent roof cover would make it the preferred choice for span articulated roofs. Fabric forms for steel and ferrocement roofs is the kind of emerging technology, that offers architects and engineers the opportunity to experiment with forms and create exciting solutions to conventional design problems. However, design of fabric forms for steel and ferrocement roofs utilizing codes and standards have not developed. This issue has to be addressed and codes & standards must be proposed, discussed and implemented by professionals and regulators.

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