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STRUCTURAL MEMBRANES IN MEXICO: TWO CASE STUDIES

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Summary. This paper describes two membrane structure projects in Mexico built with similar dimensions and materials but different climatic and structural conditions. The first project is located in Mexico City and called CUT, was built above the roofs of two existing buildings, which serve as counterweights, and has moderate wind speeds and sun exposure. The second project, meanwhile, located in the city of León, Guanajuato and called ENES León, was built at ground level and is exposed to higher wind speeds, temperatures and sun exposure, requiring the construction of a more robust foundation and anchoring systems as well as its own foundation system.

1 INTRODUCTION

Membrane structures in Mexico have rapidly grown in popularity during the first decade of this century. Specific requirements such as protection from the sun or rain, together with their visual qualities, have made this type of structural system a reference point for contemporary architecture in Mexico and a symbol of a reconciliation between architecture and engineering, form and structure, or indeed geometry and mechanics.

This paper presents and describes two projects recently carried out for the Universidad Nacional Autónoma de México (UNAM). The first, called CUT, is located in Mexico City and is intended to generate a space where students of the University Drama Center—in the Cultural Zone of the Ciudad Universitaria campus—can engage in different activities such as rehearsals or stagings, together with a terrace set aside for a café. The second, called ENES León and located in the city of León, Guanajuato, is intended for a cafeteria within a new campus housing the National School for Higher Studies, León. Here, temperatures rise to 40°C in summer. The two projects cover an average area of 344 m^2.

The description and study of the two constructions follows a clear order based on the range of variables implied by the methodology covered by the design process at the Structures Lab of the UNAM's Architecture Faculty. This may be summed up as follows: 1. Considerations of architectural and structural design, 2. Formfinding, 3. Structural analysis, 4. Membrane, 5. Load-bearing structure with foundations, hauling system and anchors, 7. Installation. It concludes with a table of comparative data for the two case studies including covered and developed areas, weights and wind speeds taken into account for the structural analysis.

2 CUT PROJECT – UNIVERSITY DRAMA CENTER

The University Drama Center – CUT is located in the Cultural Zone of the Ciudad Universitaria campus in the UNAM, in Mexico City. This space is dedicated to teaching performing arts and is one of the leading venues of its kind at a national level. In 2011 the Structures Lab of the UNAM's Architecture Faculty was asked to develop a project for the construction of a tent structure for the center, with the specific requirement of covering an area between two buildings of differing heights to create a space where students are able to engage in a range of activities.

Once these requirements had been analyzed, it was decided to design a roof capable of covering the space between the two buildings and taking advantage of their differing heights in order to create an area above the lower one where a café could potentially be installed, offering excellent views of the south of the Valley of Mexico.

2.1 Considerations of architectural and structural design - CUT

The architectural design was developed by architects Juan Gerardo Oliva Salinas and Marcos Javier Ontiveros Hernández and the structural design by engineer Juan José Ramírez Zamora. The typology of the roof comprises elliptical cones made up of floating posts ending in lanterns, allowing the passage of the sun's rays in order to create a play of light and shadow inside. It covers a floor area of 417 m^2 with an actual surface area of 488 m^2. The total weight is 28.7 kN, resulting in a weight of 58.8 N/m2. The shape was worked out using MPanel© software and the static wind analysis was carried out using a specialized computer program for matrix analysis. The load considerations for the static wind analysis are: dead weight, 10.8 N/m2; pre-tensioning, 294.3 N/cm2 and a design for wind speeds up to 96 km/h, equivalent to 26.7 m/s. This analysis was carried out in reference to Mexican norms set out in the Federal District Construction Regulations (RCDF) and the Complementary Technical Standards (NTC), as well as the manuals of the Federal Electrical Commission (CFE), the American Concrete Institute (ACI 318-05), the American Institute of Steel Construction (AISC), the American Welding Society (AWS) and support from the Design Guide for Surface Tensile Structures. (Fig. 1)

Figure 1: Exterior and interior views

2.2 Membrane - CUT

The manufacturing of the membrane was carried out using the high-frequency process on a textile composite made of pre-stressed polyester threads covered in PVC and a layer of highly-concentrated Fluotop T-2 PVDF compound on the top surface and of weldable PVDF on the reverse, to provide improved resistance to pollution on the inside of the material, as well as the following characteristics: breaking strength (warp-weave) of 420/400 daN/5cm, tear strength (warp-weave) of 55/50 daN, translucency 8%, solar diffusion 6%, solar absorption 16%, solar reflection index 78%, and acoustic attenuation index 15 dBA. It has a weight of 1050 g/m2, which for the total area of the roof comes to 5.03 kN (513 kg).

2.3 Structure - CUT

The structure comprises 4 main elements: 1. floating posts with lanterns, 2. tensioning framework, 3. corner posts, and 4. anchors to steel and/or concrete structure. It was manufactured using structural steel type ASTM-A36, with a yield strength of 250 MPa, and with a hot-dip electrotyping finish using OC tubular profiles in the following sizes: 4” (114 x 6.02 mm), 3 1/2” (102 x 5.74 mm), 3” (89 x 5.49 mm), and 2 1/2” (73 x 5.16 mm), together with purpose-designed elements made of steel plates in the following thicknesses: 3/8” (9 mm), 1/2" (12.5 mm), and 3/4” (19 mm). The lanterns are ogival and based on an elliptical frame supported by a pair of branching, floating posts built from tubes with variable section sizes and a cover made from sheets of solid polycarbonate (plexiglass). The total weight is 17 kN. (Fig. 2)

Figure 2: Load-bearing structure with floating posts and membrane-tensioning details

2.4 Anchors - CUT

The membrane structure is supported on the two existing buildings, which serve as a counterweight. For this reason different anchoring systems were designed according to the specific site tensile forces (in the case of cables) and compression forces (in the case of articulated posts) would be applied. The following figures illustrate two specific cases of anchoring to the slab and to the metal structure. (Fig. 3)

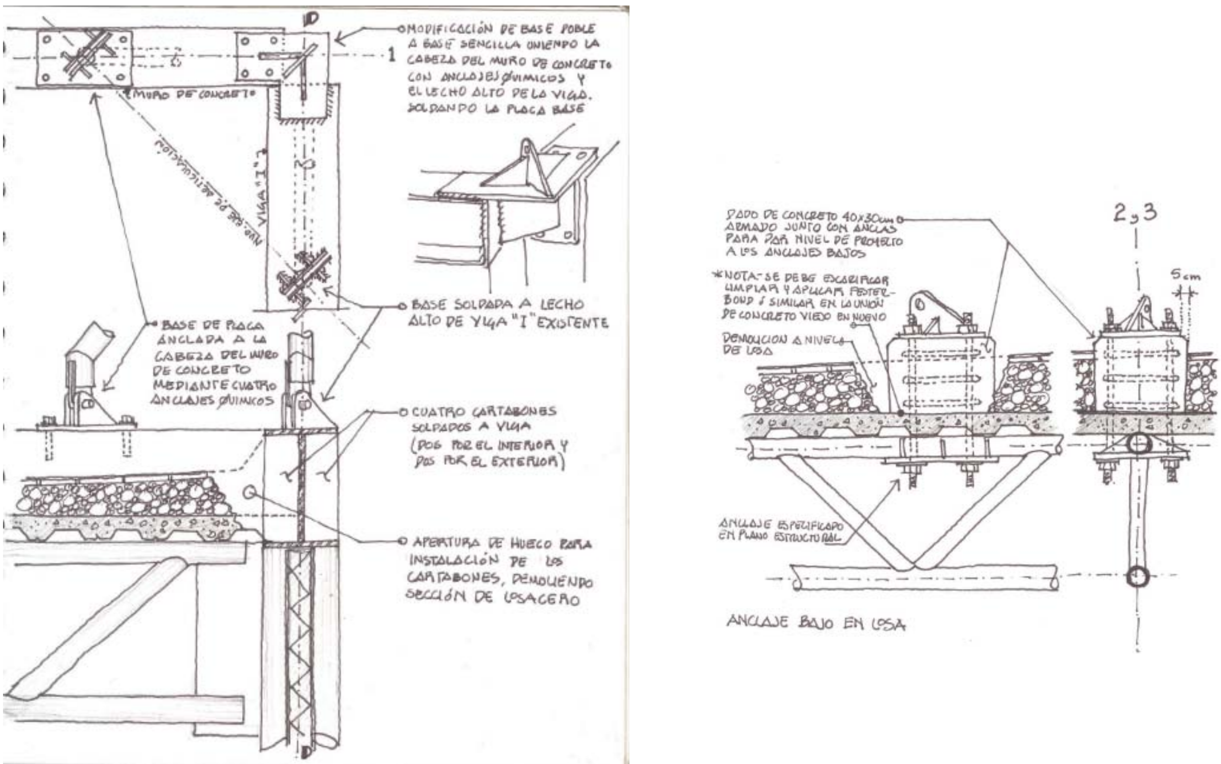

Figure 3:Anchors detailings

2.5 Installation process - CUT

The roof was raised using a crane with a beam-cable system connected to the two lanterns. In this way it was possible to raise them to their final position to connect the system of 8 cables and 6 anchoring points that support the floating post, followed by the membrane in the elliptical rings attached to these points, together with the 8 perimeter anchoring points on the buildings. (Fig.4)

Figure 4: Installation of posts and membrane with the help of a crane

3 ENES LEON PROJECT – UNIVERSITY CAFETERIA

The Universidad Nacional Autónoma de México is currently developing a number of campuses in different states around the country. In the city of León, Guanajuato, a major zone of industrial development famous for its footwear industry, work has begun on one such campus with the construction of the National School for Higher Studies, expected to be completed in the next ten years with capacity for 18,000 students.

3.1 Considerations of architectural and structural design - ENES León

The architectural design was developed by architects Eric Valdez Olmedo and Fernanda Gómez Loyo and the structural design by engineer Juan José Ramírez Zamora. Due to the location of the new campus on the outskirts of the city, a need arose to create cafeterias where students, faculty and administrative staff can eat without the need to travel into the city. The dining area covers a circular area measuring 328 m^2 with space for 108 seats, to include two retail premises and washrooms in a reinforced concrete block. The specific requirement was for the construction of a lightweight roof to protect from rain and the powerful sun that can lead to temperatures of up to 40^{o}C (approximately 104^{o}F) in the summer. It covers a floor area of 272 m^2 with an actual surface area of 345 m^2. The total weight is 205.7 kN, resulting in a weight of 588.6 N/m2.

The roof is a tensile structure with a radial typology of ridges and valleys and a total of ten alternating points converging on a central ring; five supported on the block housing the retail premises and five at ground level. The shape was worked out using Easy© software and the static wind analysis was carried out using a matrix analysis program. The load considerations for the static wind analysis are: dead weight, 10.8 N/m2; pre-stressed, 98.1 N/cm2 and a design for wind speeds up to 140.1 km/h, equivalent to 38.9 m/s^2. This analysis was carried out in reference to the standards set out in section 2.1. (Fig. 5)

Figure 5: Exterior and interior views of the dining area

3.2 Membrane - ENES León

The manufacturing of the membrane follows the same characteristics as the previous one (see section 2.2) and has a total weight of 3.6 kN.

3.3 Structure - ENES León

The structure comprises 2 types of posts with a Y-shaped geometry, divided into sections to facilitate transportation: 1. Perimeter posts in the dining area, and 2. Perimeter posts on the reinforced concrete block. The Y1 type posts were fabricated using ASTM-A36 steel, with a yield strength of 250 MPa, using OC tubular profiles in the following sizes 8” (219 x 8.18 mm) and 4” (114 x 6.02 mm). The Y2 type posts used 6” (168 x 7.11 mm) tubular profiles, as well as purpose-designed elements made of steel plates in the following thicknesses: 3/8” (9 mm), 1/2" (12.5 mm), and 3/4” (19 mm). The finish for the structure uses an anticorrosion primer and a polymer varnish-based paint. The total weight is 20.35 N. (Figs. 6 and 7)

Figure 6: Y-post system in dining area and building roof

Figure 7: Membrane tensioning system with anchors to ground and load-bearing structure

3.4 Foundation - ENES León

The foundation for the structure was built using reinforced concrete with a compression strength of 25 MPa and ASTM-A709 reinforcing steel, with a yield strength of 690 MPa. it comprises three types of isolated spread footing foundations located at the level of the dining plaza with a finish grade of -1.20 m: Z-1, Z-2 and Z-3. The first, Z-1 measures 2.5 x 1.8 x 0.20 m with a 0.50 x 0.50 x 1.00 m block and weighs 27.63 kN. Z-2 measures 2.5 x 2.5 x 0.20 m with a 0.50 x 0.50 x 1.00 m block and weighs 36.04 kN. Z-3 measures 1.40 x 1.40 x 0.20 m with a 0.40 x 0.40 x 1.00 m block and weighs 13.26 kN. 11 blocks are located on the building connected to the reinforced concrete structure measuring 0.35 x 0.35 x 0.40 m on average. The foundation as a whole weighs 192.1 kN. (Fig. 8)

Figure 8: spread footing foundations for post Y1 in loadbearing structure

3.5 Installation process - ENES León

The installation of the structure and the membrane was carried out with the help of a crane. In the case of the structure auxiliary plates were placed on top of the posts for the hoisting maneuver, placing the element in its final position and carrying out the necessary welding. In the case of the membrane, the hoisting was carried out from its central section with a fastening system adapted to the tensioning ring where the cables of the radial ridges and valleys converge. Once raised into position, it was possible to hold the ten perimeter points and execute the tensile process. (Fig. 9)

Figure 9: Installation of posts and membrane with the help of a crane

This project is part of the research carried out by the Structures Lab of the UNAM's Architecture Faculty, entitled: Bamboo and flexible membranes–PAPIIT IN-404611, in conjunction with the University College of London (UCL), as a case study for examining the possibility of an alternative, bamboo-based structure.

4 TABLE WITH COMPARATIVE DATA

		CUT	LEON
1.	Roof surface–projected on the ground	417 m^2	272 m^2
2.	Surface area in space	488 m^2	345 m^2
3.	Weight of membrane	5.03 kN	3.55 kN
4.	Weight of loadbearing structure	17.01 kN	20.35 kN
5.	Total weight of structure and membrane	22.04 kN	23.9 kN
6.	Weight of structure and membrane	37.08 N/m^2	69.26 N/m^2
7.	Weight of structure	34.83 N/m^2	58.86 N/m^2
8.	Weight of foundation with concrete	10.6 kN	192.1 kN
9.	Total weight	28.7 kN	203 kN
10.	Design for wind speeds	26.7 m/s	38.9 m/s
11.	Software for formfinding	MPanel©	Easy©

5 CONCLUSIONS

- In both structures there is an average difference of 144 m2 between the area covered and the actual surface area of the membrane.
- The manufacturing conditions are the same except for the finish to the structure.
- The location affects the design for wind speeds and therefore the reactions of the ENES León project structure are considerably higher.
- The volume of concrete for the foundation and thus the weight by area unit is considerably higher given that the in the case of the CUT, the building functions as a counterweight to the roof, while in the case of the ENES León, it was necessary to build spread footing foundations for the counterweigh to the structure. Thus the weight of the foundation is not a relevant aspect for the comparative analysis.
- This work, which reveals the joint efforts between designers, builders, and clients to maintain and improve the quality in the design and construction of tent structures, contributes to the promotion of architectural criticism, the dissemination of knowledge and the state of art in the design and manufacture of membrane structures in Mexico.

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