Optimizing Tensile Membrane Design utilizing CFD

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Abstract

CFD is a process that assists designers in optimizing the design configuration of a Tensile Membrane structure. In the main small to medium creative tensile projects are not feasible to wind tunnel test due to both time deadlines and financial constraints. While forms including Hypar, Barrel Vault, Monopitch and Duopitch are documented in various international codes the conic shape, multiple structure configurations, and freeform canopy profiles are not. The use of CFD coupled with FEA provides a cost effective solution in determining the anticipated wind action on complex canopy profiles. Identifying wind pressure co-efficient reactions within a canopy allows for the accurate nomination of structural steel supports and foundation detail thus alleviating the issue of either over compensating or underestimating design criteria.

Introduction

The Light Weight Structures Advisory Service core scope of work is the design and engineering of small and medium sized tensile membrane projects utilizing Shade Cloth, PVC and PTFE fabrics. To develop tensile structures with maximum design efficiency our organization has coupled Computational Fluid Dynamics (CFD) to our existing Finite Element Analysis (FEA) package.

To incorporate CFD in the design process a Fluid Structural Interface (FSI) was developed under the direction of Dr. Bill Daniel, Head of Mechanical Engineering, University of Queensland. The FSI utilizes the first iteration and pressure maps the derived canopy loads from the CFD to the FEA program – the canopy profile deforms accordingly. This deformed shape can be imported back into the CFD simulation to perform second and subsequent iterations. This FSI process has gained recognition with the Australian Technology Showcase.

Why use CFD

Tensile membrane design can be optimized with the use of CFD linked to FEA. Using this combination of technologies the design professional is able to construct a geometric model within 3D modeling software while taking into consideration surrounding buildings and landscape. When the simulation has run and the results reviewed, the 3-D model can be adjusted and the simulation rerun until the optimized tensile profile is achieved resulting in a tensile membrane structure with maximum aesthetic appeal and minimal support structure.

How is Computational Fluid Dynamics (CFD) defined,

- *Computational - having to do with mathematics, computing*
- *Fluid Dynamics - the dynamics of things that flow*

> *CFD is a sophisticated computationally-based design and analysis technique. CFD software gives the user the power to simulate flows of wind through computer modeling. Using CFD software, the user can build a 'virtual prototype' of the system or device that is to be analyzed and then apply real-world physics to the model. The software will provide the user with images and data, which will predict the performance of the design.*
>
> *(http://www.fluent.com/solutions/whatcfd.htm 7/10/2009)*

CFD is an alternative to wind tunnel tests. In the main small to medium creative tensile projects are not feasible to wind tunnel test due to both time deadlines and financial constraints. Coupled CFD with FEA provides the user a cost effective solution in determining the anticipated wind action and pressures on canopy profiles. CFD has been shown to be a reasonable prediction of wind pressure distributions. It conceivably could replace some wind tunnel tests (Susila I G 2000).

Various international codes of practice including AS1170.2002 (Australia) ASCE7-05 (United States), BS6399 (British) Euro Code 1 EN-1991 (European) identify canopy profiles including Barrel Vaults, Hypars, Mono Pitch and Duo Pitch and may be used as a guide enabling the designer to determine the wind action on the abovementioned canopy profiles.

Tensile Structures are unique in their design. Within certain constraints the design of Tensioned Structures are only limited by the designer's imagination. Often the free form design of tensioned roof structures results in canopy profiles that do not fall within the guidelines of international codes. This is particularly evident when a designer is utilizing the conic profile which is not referenced. Conic profiles are commonly used due to the structures stability and aesthetic appeal; however, even small changes in the profile of a conic canopy can significantly alter the loading on the roof canopy, and the zonal distribution of that loading (Burton J 2004).

Conic Structures and CFD

When choosing to utilize the conic form deciding whether the bail ring section of the canopy should be open or closed is a key design criteria which must be decided at the outset of the project as each alternative has a significant influence on the wind pressure applied to the canopy.

Free Standing Conic Structures and CFD

CFD visualizations represented in Figures 1 and 2 illustrate the airflow through the bail ring section of the canopy. Without the use of CFD visualization the importance of this design criteria may not be recognized. Figure 3 illustrates the pressure mapping applied to the FEA model from the CFD simulation.

By utilizing the coupling of CFD to FEA the pressures are mapped exactly face by face not averaged as would be normal practice when constructing an FEA model without the link to CFD.

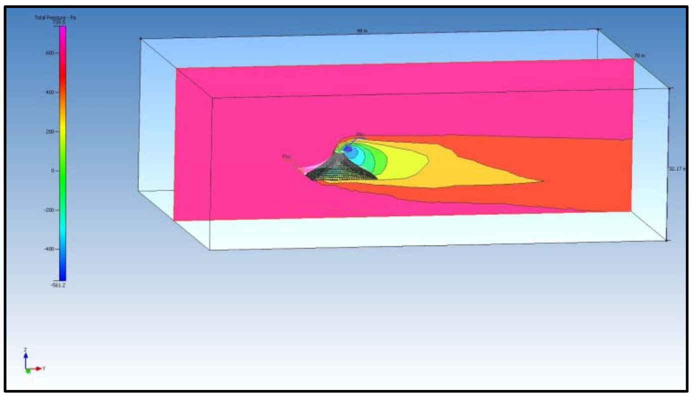

Figure One: Free Standing Square based single Conic with bail ring open . Visualization slice from CFD software showing wind simulation over a conic profile with open bail ring.

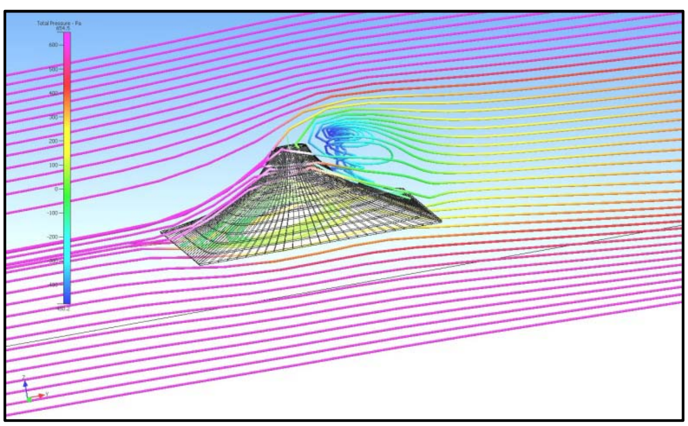

Figure Two: Free Standing Square based single Conic with bail ring open. Particle Trace from CFD software showing wind turbulence over a conic profile with open bail ring.

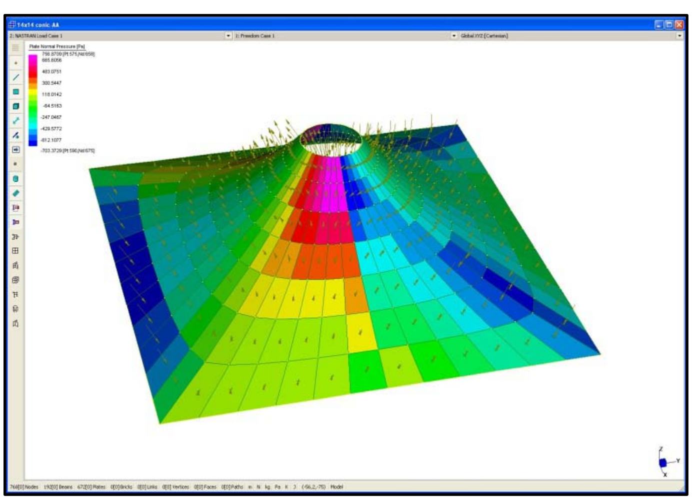

Figure Three: FEA Model of Free Standing Square based Single Conic. Utilizing the FSI the CFD simulation results are pressure mapped directly onto the canopy profile within the FEA package ready for analysis.

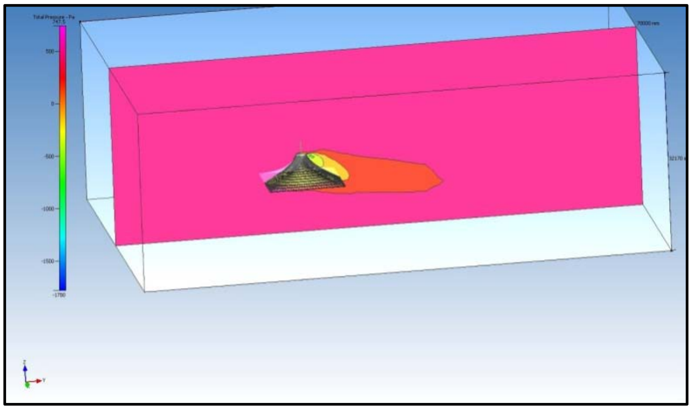

Figure Four: Free Standing Square based single Conic with bail ring closed. Visualization slice from CFD software showing wind simulation over a conic profile with closed bail ring.

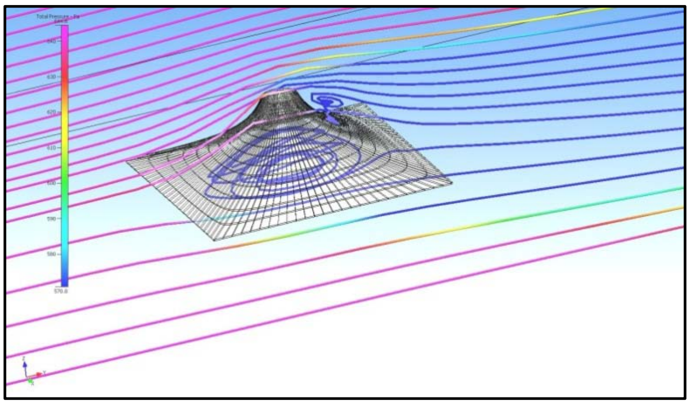

Figure Five: Free Standing square based single conic with Bail Ring closed. Particle Trace from CFD software showing wind turbulence over a conic profile with closed bail ring.

Double Conic Structure attached to Building and CFD

Figures 6, 7, 8 and 9 highlight the influence of mounting a double conic structure to a building. The wind action on both the tensile conic structure and the building surrounds is illustrated. The Particle Trace Visualization (Figure 8) identifies the airflow and turbulence around the front exterior. Large buildings significantly affect airflow and influence ground level wind speeds around their base. This can lead to the development of very high wind speeds around the base of a building, rendering certain areas unsafe for pedestrians. On a smaller scale, moderate wind speeds may make areas uncomfortable and therefore unsuitable for a street café (Palmer G, Vazquez B, Knapp G, Wright M, Happold B 2003)

Figure Nine highlights the wind turbulence effect onto the face of the building. This style of visualization assists the building designer to compensate for the additional stresses transfer to the building.

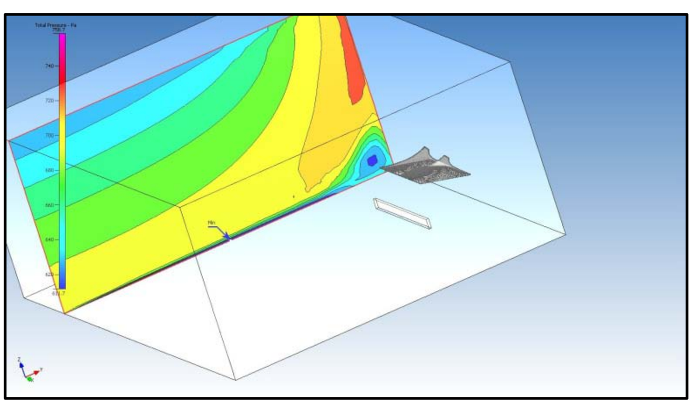

Figure Six: 80sq mt Double Conic Canopy attached to building. All weather entrance canopy to residential apartment building.

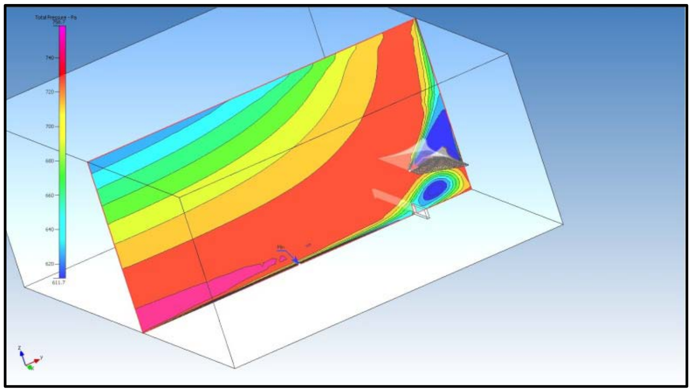

Figure Seven: Visualization Slice illustrating the high and low pressures generated by wind and topography influence on the double conic structure, building and surroundings.

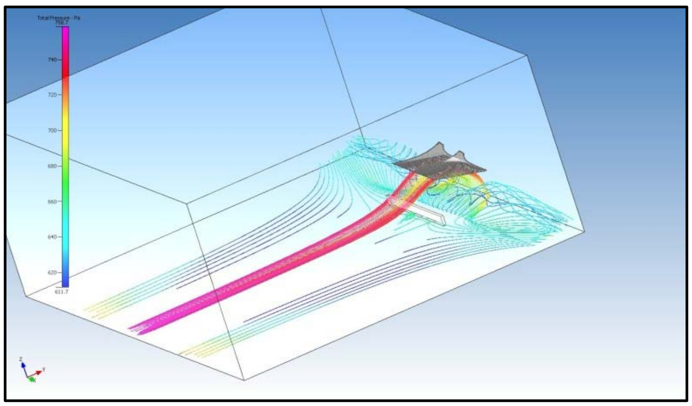

Figure Eight: Particle Trace Visualization highlighting wind turbulence generated along lower level front exterior. Large buildings significantly affect airflow and influence ground level wind speeds around their base. This can lead to the development of very high wind speeds around the base of a building, rendering certain areas unsafe for pedestrians. On a smaller scale, moderate wind speeds may make areas uncomfortable and therefore unsuitable for a street café.

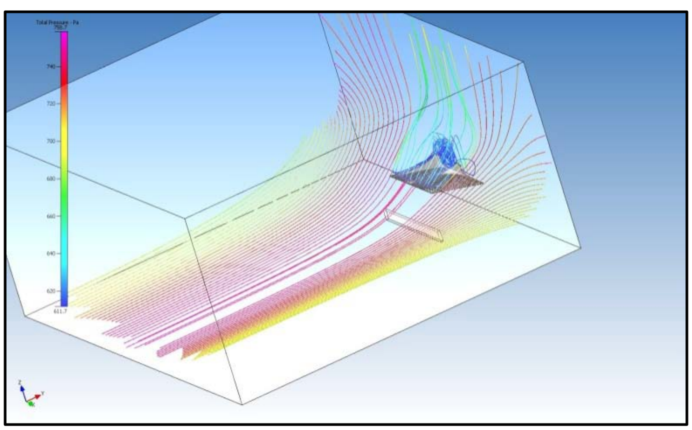

Figure Nine: Higher Level Particle Trace highlighting the wind turbulence effect onto the face of the building. This style of visualization assists the building designer to compensate for the additional stress transfer to the building supports.

Figure Ten: Built Structure 20/10/09

Project Name: Spring Hill Suites

Miami Florida USA

Project Size: 80 sq mts

Multiple Configuration Barrel Vault and CFD

Projects such as Shopping centre car park situations, utilize multiple structures in close configuration. Information for designing Barrel Vault structures is available in various international codes but the down wind effect of a multiple configuration is not documented. CFD simulation illustrates the wind influence and turbulence created when structures are constructed in close proximity and highlights the wind influence multiple structures have on the surrounding landscape. This phenomenon is referenced in Figures Eleven and Twelve. Figure Thirteen identifies the pressure mapping applied from the CFD simulation to the FEA model. This process contributes to the determination of structural steel supports and foundation detail.

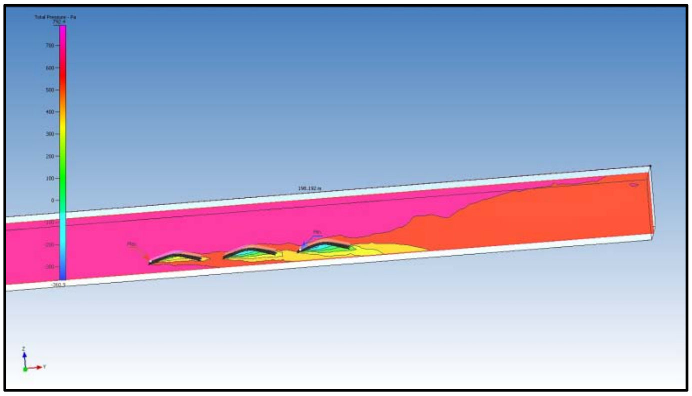

Figure Eleven: Multiple Configuration Barrel Vault Car Park Structures. Visualization Slice illustrating the wind effect in a multiple structure configuration.

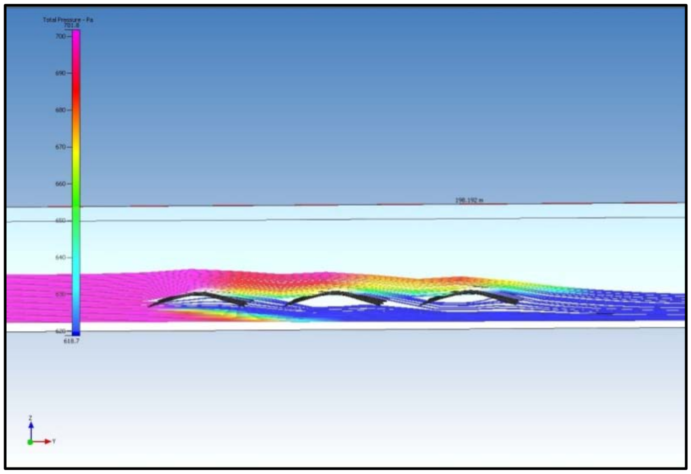

Figure Twelve: Particle Trace illustrating the influence multiple structures have on the downwind landscape.

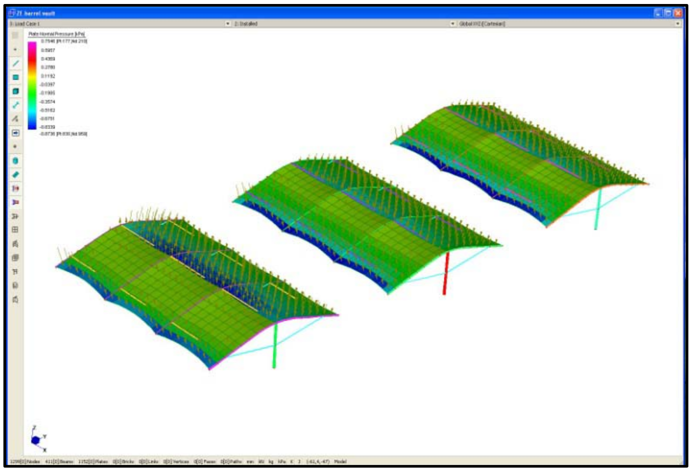

Figure Thirteen: FEA Model of multiple Barrel Vault structures. Pressure mapping applied from CFD simulation allows for accurate nomination of structural steel supports and foundation detail thus alleviating the issue of either over compensating or underestimating design criteria.

Free Form PTFE Tensile Membrane Structure and CFD

The Free Form PTFE Tensile Membrane Structure represented in Figures 14,15,16 has dimensions of 30.9 mts (L) x 12.3 mts (W) x 10.5 mts (H). The CFD simulation illustrates the turbulence created when tensile sails are grouped together. Figure 15 highlights the prediction of turbulence. Nominating the wind pressure co-efficient within a structure of this style is difficult utilizing information within international codes. CFD allows for numerous simulations to be conducted from various wind directions. This is an important consideration as each profile of the structure is unique and will offer a different set of results. CFD simulation results coupled to FEA allow for the determination of structural steel supports and foundation detail. The numerous load cases generated from each wind direction allow for worst case analysis of the structure.

Additionally as demonstrated in Figure 14, it is evident the 10.5 mt height of the structure has significant influence on the surrounding landscape. This information is invaluable to the landscape designer who can compensate accordingly.

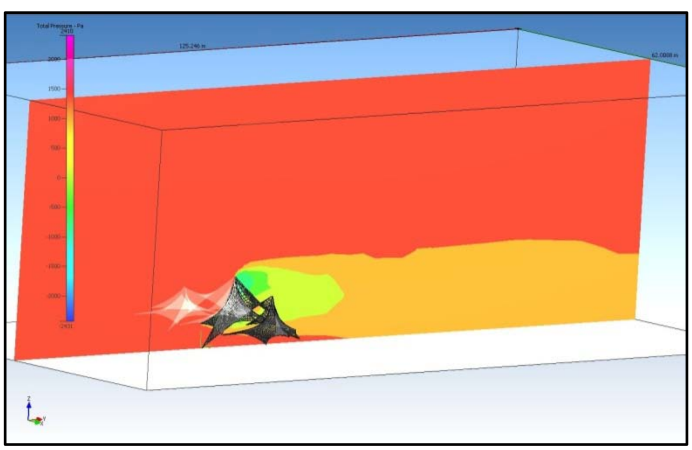

Figure Fourteen: Visualization Slice of 318 sq mts of PTFE tensile sails covering an outdoor recreation area in the UAE. The wind influence multiple structures have on the surrounding landscape is highlighted.

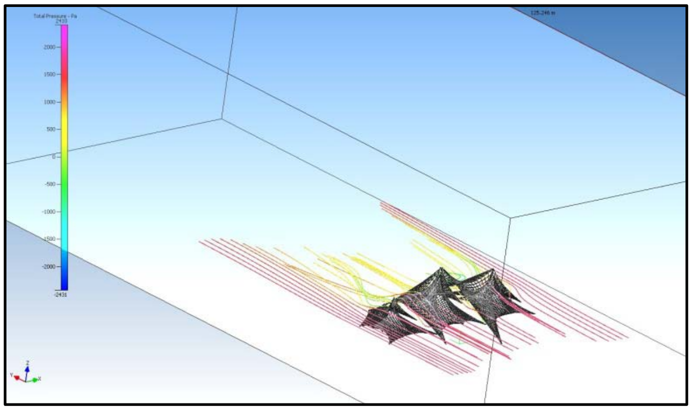

Figure Fifteen: Particle Trace highlighting wind turbulence within a multiple sail configuration.

Figure Sixteen: Built Structure 22/10/09

Project Name: YAS Island BBQ Area

Abu Dhabi UAE

Project Size: 318 sq mts

Conclusion

The use of CFD coupled with FEA provides a cost effective solution in determining the anticipated wind action on complex canopy profiles. Identifying wind pressure co-efficient reactions within a canopy allows for the accurate nomination of structural steel supports and foundation detail thus alleviating the issue of either over compensating or underestimating design criteria.

The benefits of utilizing coupled CFD simulation and Finite Element Analysis include,

1. CFD model simulations can be run to include all relevant wind directions as well as geographic topography and terrain categories.
2. CFD offers a cost efficiency over wind tunnel testing as there are no set up costs for scale models and the operation cost of the wind tunnel testing facility
3. CFD offers timely results due to the ability to model and run simulation as opposed to the weeks of preparation of wind tunnel testing.
4. CFD offers design flexibility as changes to the canopy profile and supporting structure can be made and the design optimized.

CFD is a process that assists designers in optimizing the design configuration of a Tensile Membrane structure. Pressure mapping the output results from the CFD simulation to the FEA model allows for accurate nomination of structural steel supports and foundation. CFD is a tool for predicting what will happen under a particular set of circumstances.

References

Burton J and Gosling PD (2004). “Wind loading pressure coefficients on a conic shaped fabric roof-Experimental Methods.” *Journal of the International Association for Shell and Spatial Structures: IASS* Vol 45 No.3 pages 183 – 189

Palmer G, Vazquez B, Knapp G, Wright M, Happold B (2003). “The practical application of CFD to wind engineering problems.” *Eighth International IBPSA Conference* pages 995 – 999

Susila I G (2000) *“Wind load predicting; how could CFD replace Wind Tunnel Test?”* pages 1-15

(http://www.fluent.com/solutions/whatcfd.htm 7/10/2009)