

# ***Fabric Structures in Australia***

## ***Growing our industry through technology***

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*Sept 2009*

## **Introduction**

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Australia has many spectacular fabric structures that are comparable to iconic structures around the globe and amply demonstrate the ingenuity and professionalism of parts of the Australian industry.

Unfortunately, there is a much larger number of “less than spectacular” structures that have sprouted up across our landscape over recent years. These structures reflect poorly on the industry and are adversely affecting future growth potential.

## **Objective**

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The objective of this paper is to share experientially based observations, solicited comments and a plethora of feedback from a wide cross section of the fabric structure and shade industry on the current state of the industry, and to suggest practical ways:

- Individual companies can understand and improve knowledge of ‘how the technology works’.
- Of ensuring that both the structures and the materials used in many LW shade structures provide many years of satisfactory service through good design, fabrication, and installation.
- The industry can work together to address the growing consumer concerns regarding quality and safety of our products.
- Of replacing the presumed or assumed knowledge or lack-there-of with good engineering practices by the sharing of the limited amount of good empirical, experimental and experiential knowledge that exists within the industry.

## **Background**

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### **History**

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To fully appreciate where we stands today, we first need to review the development of the shade industry and consider all the factors that have influenced the paths we have taken and the choices that we have made.

- Evolution vs. replication

The majority of our fabric (shade) industry has grown by new businesses copying the work others, who have copied the work of a few early entrepreneurs with little if any improvement or investment in R&D. Without the technical understanding of why a thing was made the way it was, more often than not, the resulting “copies” will turn out to be more and more inferior. We need to invest in developing knowledge and technological “know how” if we want the industry to evolve and improve.

- No empirical reference

There has been little in the way of 'exact' engineering like there is for conventional prismatic solid-clad structures.

- No formal training

The industry has by and large been left to its own devices to trial-and-error what works with little in the way of formal testing. Experiential knowledge is no substitute for experimental testing if there is no feedback mechanism into the experience from what actually works under extreme or design conditions. i.e. – we can keep doing what we've been doing believing it works if there is never any come-back on us for failures, or if it's never been exposed to the extremes it's been designed for.

The complexities of balancing size, shape, cable tensions, load reactions, knowing what pressure coefficients to apply or how membranes behave under dynamic wind conditions are little known to the newcomer or novice in the industry, and many local consulting engineers in this cottage industry don't have these readily at hand when called upon to provide the essential engineering services.

Nothing in the way of design or installation of these types of LW structures are covered in any TAFE or building courses and for years, sadly for many, it's been a case of the blind leading the blind.

### The market today

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So we find ourselves today in a "loosely" regulated relatively "low to medium cost" industry comprising of a growing number of businesses wanting a slice of what appears to be a relatively easy low-tech "pie" with the hallmarks of our industry as follows:

- Competitive

With high volumes of low-tech solutions to shade, and with little in the way of industry or building regulation in the past to control this phenomenon, many shade companies compete on price alone – driving down quality.

The market even has cheap 'D.I.Y.' shade solutions from many hardware chains.

Suppliers from Asia have now come into the market, providing highly competitive prices on the more familiar standard shade structures further depressing prices.

- Cottage Industry

Many simple shade structures lend themselves readily to a cottage industry, avoiding the usual overhead costs born by the more professional and larger companies.

Installers need little more than a 'Ute and a shovel' and fabricators can get away with the minimum of a sewing machine and a garage floor. Leading this crew of subcontractors is the sales organisation which requires little more than a phone, a yellow pages advert, a car and a business card.

The lack of investment in resources keeps organisations "lean and mean", however this lack of real commitment makes it very easy to decide to simply "pull the plug" and wind up a business leaving clients without any real warranty. This approach to business also precludes real investment in learning and understanding the technology or investing in research and development.

- Rapid growth

The combination of mandated provision of sun shade, low barriers to entry and with Governments injecting millions into school facilities, it's natural that we've seen such a massive influx of new shade providers in the industry. In Victoria for example, 10 years ago the Shade Sails & Gazebo

section in the Yellow Pages was represented within a single column – today Shade Sails alone consumes more than 4 pages.

- Little Regulation

Unlike nearly every other aspect of manufacturing, fabrication, production or building construction, there is little in the way of regulation or certification of approved providers in the shade industry. Only recently has there been the need even to provide engineering certification for these structures. For years, many of these structures have slid in ‘under the radar’, having been exempt from requiring building permits in many states. As an example, here in Victoria there are more than 300 companies “doing” shade – approximately 5% are Registered Building Practitioners despite this being a condition of the BCA.

Up until now, one didn’t require a building permit for a simple shade structure. Even the larger framed shade structures did not require a permit in schools. Often companies experienced more difficulty with fabric colour selection and town planning requirements than they did with the structure complying with local building departments.

- Copying limits growth

Shade was easier to sell in the past when there were fewer structures that were unique and mostly attractive. Nowadays, with the proliferation of low-tech shade structures, people perceive them as being a ‘cheap-and-nasty’ shade solution, and many structures certainly show themselves as being less than attractive or desirable. This is compounded by a tendency for new entrants into the market to copy existing structures and typically to copy the simpler low-tech structures.



Note the lack of fabric tension in the above shade sails, probably due to poor patterning and insufficient prestress.



Note the deformation in this frame. This structure failed and had to be replaced.

- Recent accidents

As a result of several highly publicised shade structure failures within schools, Education Departments in several states reacted and the result has been unfavourable for our industry.

There are legal requirements to obtain suitable licenses to operate equipment which can cause harm in most areas of industry except, it appears, the shade industry. Today, we have unlicensed and unqualified individuals and companies welding together steel frames and using un-proven and un-engineered connectors and fittings that have the potential to harm, or even kill our children.

While we should welcome a degree of regulation and the need for providing proper engineering, S.A. has effectively outlawed shade structures in schools and N.S.W. are considering following suite. As an industry, we need to respond positively and quickly to counter this move.

Consumer perception of the shade industry is one of wariness and hesitation as the alarming press stories of death and injury relating to shade structures and a plentiful supply of poor reference structures conspire to undermine our collective best efforts.



This hip and ridge “Y piece” has suffered sudden and catastrophic failure under wind load.



Note the shallow concrete footing to the left. This post and footing was completely lifted clear of the ground during failure. The original structure covered a large primary school playground area approximately 140m<sup>2</sup>.

**NC: Man dies in bizarre umbrella accident**

Posted: Aug 12, 2008 02:48 PM

Updated: Aug 12, 2008 09:45 PM

Posted by Jeff Will

A 32-year-old man was speared through the head with one of the patio umbrellas at his pool.

He was laying out by the pool at his North Carolina apartment complex when the umbrella fell on top of him.

Exactly what happened to cause the umbrella to fall is still unclear, but neighbors said it might have been the strong winds.

The apartment complex has removed the umbrellas.

Few really appreciate the force wind can have on even a small lightweight structure such as a patio umbrella.

Notice the reaction of management. This is similar to what we are experiencing in S.A. and N.S.W. schools.

**Parents fear shady works**

Wednesday, January 21, 2009  
© The Cairns Post

**PARENTS** fear shoddy construction work caused 6m poles to come crashing down on an Innisfail school's play area, days before their children resume classes.

The collapse of a shade structure at Mena Creek State School, south of Innisfail, is being investigated by Education Queensland.

Relieved parents were thankful the accident happened in the school holidays.

The shaded area was opened last September.

It is believed to have been built by contractors.

Residents reported windy conditions when the structure, over a tennis court, collapsed in the early hours of last Tuesday morning after a day of heavy rain across the Far North.

But they described it as "normal wet season weather".

The incident comes as the Queensland Ombudsman investigates claims of unsafe repairs to shade structures at schools in the wake of Cyclone Larry, after warnings from a Cairns school principal about potentially deadly faults in shade sails replaced by contractors working for government building services provider QBuild.

A spokesman for the ombudsman would not comment on the investigation yesterday, which started in November and is believed to be dealing with complaints from several Far Northern principals.



**Safety concerns:** Parents are worried shoddy workmanship may be to blame for the collapse of a shade cloth at Mena Creek State School.

The most concerning feature of this article is the apparent severity and extent of this problem, with statements and inferences such as... only "opened last September"; "normal wet season weather"; many "claims of unsafe repairs"; "warning from a Cairns school principal"; "complaints from several Far Northern principals" and "Parents are worried shoddy workmanship...". This should be a wake-up call to our industry as a whole.



This was an old shade structure in a school that had a new fabric membrane fitted. It was relatively flat with little height variation between poles, and potentially significant lateral loading. Failure was at the column bases as seen below.



Mandatory school shade structure audits are well justified but can potentially miss unseen dangers. Issues of HD bolts at or below ground level where severe corrosion can go unseen must comply with performance requirements of the BCA and adequate corrosion protection to AS4100.



This shade structure had inadequate size poles. The close-up below shows localised failure under bending at the top of the footing. Other shade poles in this municipal pool show excessive bending. Note also the lack of tension in the shade sail in the background.



Bending failure of the pole at ground level.



The above photos show the result of two large PVC shade sails that were attached to a common anchor point on the brick wall of a house. Failure of the brickwork to resist the large “pullout” loads caused the brickwork to collapse. Brickwork still attached to the cables swung down and into the living room through the glass patio doors below while a family was present inside. The potential of a fatality is evident. One would have to question the “engineering” or lack there of.

**Our industry is under the threat of extinction and it is largely self-inflicted. We're now at a stage where we must improve the quality of our industry if we want sustainable growth.**

## Technical Challenges

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To enable companies to produce a higher standard of product that is capable of withstanding the test of time, there is a need to better understand and tackle the complexities of the technology necessary for improved design. Correct design and implementation is a complex process with more stages and interactions between them than many appreciate. Some of these factors include the following:

- Design: – Designers need to better understand and master some essential aspects including:
  - Form Finding
  - Permissible (Anticlastic/Synclastic) forms
  - Inherent stiffness resulting from correct form

The proper attention given to these aspects will ensure the fabric retains its shape and form without failing due to either overstress, (being over-tensioned and forced to create a poorly designed form), or from chafing and wearing, (due to fatigue under relaxed or too loose a condition.)

Some simple and general rules of thumb and design guidelines, coupled with access to some good software and practice will help overcome these problems.

- Engineering: – This is a critical factor that we will focus on in this paper, but briefly includes:
  - Determining applicable Loads, Pre-stress, and final Limit State Design Strength and Serviceability Loads on both the fabric and the structure
  - Determine Reactions and subsequent structural behaviour
  - Design Structure/Critical Detailing/Connection

The whole process is iterative and requires simultaneous resolution of several issues of:

- Geometry
- Form
- Detailing/Connections
- Structure
- Tensioning
- Installation efficiency.

This is somewhat counter-intuitive when compared to more traditional approaches to construction. A tensile structure requires that the method of fitting and tensioning the membrane be resolved at the same time as locating efficient connection points. Furthermore, the final form of the membrane will have a significant influence on the loads, and changes in heights will impact form and reactions thereby influencing fittings/connections and structure.

Designers of tension membrane structures, regardless of the size or degree of simplicity or complexity, need to work together in partnership with engineering to enable these critical issues to be addressed satisfactorily to ensure the best outcome.

- Fabrication: – To ensure an overall successful design, fabrication of the tension membrane must include attention to:
  - Seam Design
  - Patterning
  - Computer Plotting
  - Fabric Choice

Manufacturers of fabric structures must have a good working knowledge of the materials they use, including an understanding of how the properties of different materials vary and how they behave under load.

Basic software allows designers to model forms and shapes under load and can, with experience, learn to create the most efficient fabric shape and pattern to suite the particular application.

Fabric designers can also give essential feedback to the architect and engineer before finalising details of the structure and geometry.

- Community sentiment: – As an industry, we need to address the negative publicity recently received as a result of a few catastrophic, and many other costly failures:

The LSAA could assist the industry by promoting it as a sound and confident profession and to enlighten the broader community, especially relevant bodies such as the education industry, to the benefits of L.W. structures, and to turn back the tide of blanket ‘banning’ the use of lightweight shade structures altogether.

This could be achieved by emphasising the fact that the industry has embraced a degree of regulation and is focussing on proper engineering design.

## **Engineering – (the biggest challenge)**

Given the above challenges, the remainder of this paper will focus on some essential aspects of engineering unique to our industry. For many, this is the “lynch pin” to either hindering or advancing success.

With all due respect to some of the fine engineering undertaken by some, the following adage seems to be most applicable to much of the engineering of many shade structures today:

*“Structural engineering is the art of applying loads we cannot estimate, to structures we cannot analyse, which are made from materials we do not understand, in such a way that the public at large has no idea of the extent of our ignorance.”*

*(Source unknown.)*

## **Current approach to engineering in the shade industry.**

In terms of undertaking engineering, the shade supplier has available to them the following options:

- “Do nothing”.

Use “rule-of-thumb” approach to post and footing sizes gleaned from others or from past projects that seemed to “look right”. With no past need for building permits or engineering, many businesses have flourished in a “need for shade” climate.

- Use “Shade Advisory Services”.

There are a small number of non-engineering companies that offer design services to the small fabricator, built from prior experience in the steel fabrication industry. While many of these companies offer design services including FEA and patterning software, and provide (external) engineering certification, they do not have the specialist knowledge of fabric behaviour and fabric structures.

- Employ the services of the “specialist”.

With only a few larger expert engineering firms who do specialise in tension membrane structures, the small shade structure merchant couldn't possibly justify the costs of engineering a relatively small and seemingly simple structure. A \$5,000 project cannot absorb or justify a 20% or more engineering fee.

- Use “generic” engineered structures.

To offset the need and “cost” of repetitive engineering and to streamline the sales and manufacturing process, many shade companies have set up “generic” designs to suite multiple installations. This is fraught with dangers if there is a lack of proper understanding of the engineering principles involved in determining and “using” generic wind loading criteria.

- Employ the services of a “local engineer”.

With the recent need for engineering certification of shade structures, particularly in schools and other public arenas, there is a growing trend for shade companies to employ the services of their local “non shade-specialist” consulting engineer. This has resulted in some rather unfortunate consequences as the local consulting engineer, (normally familiar with ‘domestic or commercial’ building projects), tends to approach these apparently “simple” structures by applying ‘rigid type structure loading’ with little knowledge or appreciation of the unique behaviours of membrane structures. Little attention is even given to the membrane itself, with virtually little or no fundamental membrane stress estimation, focussing only on “sizing” the steel and footings, and little or no feedback is given in relation to optimising geometric size and form for the membrane. This is not a criticism of these engineers, but rather, it demonstrates that the understanding, ability and resources to undertake proper engineering is not at the fingertips of every engineer. The many failures of fabric structure we see today are testament to this, or to the fact that no engineering was undertaken at all.

Why did this “engineered” structure fail?



Example of an engineered structure that failed on its first day in service – this was designed using a “shade advisory service”.



This is the same structure after it was “properly engineered” and rebuilt. It has now been in service for 5 years and has withstood some of Melbourne’s most severe winds in decades.

Given that we recognise these choices and accept the need to undertake “proper” engineering, and appreciating the unique and specialised skills required, we cannot simply presume that the engineer is able to provide the complete design service that is warranted. Before the industry can confidently move forward into the 21<sup>st</sup> century, the following issues need to be addressed

### Some key engineering issues that need to be addressed in our shade industry.

- Barriers to experts

To address the issue of small to medium shade structure merchants not having the capacity to employ the services of the larger and often expensive expert engineering firms, there is a lot of tried and proven techniques and guidelines mastered by the more experienced companies that could be shared or disseminated within the industry without jeopardising their competitive edge. Also helping to bridge this gap is the availability of suitable fabric design software for the small to moderate sized shade companies. The right software both aids in the development of a better understanding of the technology and behaviour of fabric membrane structures and can be used to provide the local structural engineer with better information for design.

- Limited knowledge available to the non-specialist engineering

Engineers know a lot about beams, slabs and houses, mainly because they have endless resources of well documented, tried and proven methods at their disposal. But ask them to design a shade or tension membrane structure and it’s a different matter. If they’re not a specialist tension-structure engineer, they would have to either try to research some (limited) documentation about them, (and the time required to do this doesn’t warrant the cost of the job), or they would make intuitive judgments and assumptions about their behaviour and loads, usually using rigidly clad structures as a reference (typically conservative but mostly ignorant of key influences).

When inexperienced and non-specialist engineers do attempt to provide the engineering services required for the fabric structure, it can either be under-engineered due to a lack of appreciation of the special stresses and unique dynamic behaviour of the material, or over-engineered due to the fear of litigation if it fails and the degree of 'guesswork' involved.

Either way, unless failure of the structure proves the contrary, the shade company (and client), usually assumes that the engineers must know what they are doing and trusts that the structure must be ok because it's been 'engineered.'

But the smaller shade company can acquire some good background knowledge and essential tools that can assist the engineer to properly design the structure and essential structural elements. Beyond this, it should be emphasised that the services of the more specialised engineering company should be called upon when faced with a membrane structure that clearly warrants it.

- **Generic Engineering**

There is a strong tendency for shade providers to use pre-engineered 'generic' structures to both justify the initial costs of engineering and to simplify and streamline the fabrication and supply process. This 'one-size-fits-all' carries with it inherent dangers of non-compliance.

While the use of generic engineered structures has its place, the behaviour of members and elements of 'apparent' similarity based on a comparable 'size' structure can often be quite different. This misunderstanding of the true behaviour of tension structures can lead to misuse and subsequent failures. Typical examples of this problem include the following:

- Some shade companies work with "pre-engineered" post and footing designs which were developed based on a perfect hypar of various sizes and heights. However these same tables are being incorrectly used for triangle or kite shaped sails with very different reactions.
- Hypars with insufficient twist, and with no proper control of applied pre-tensions.
- Incorrect or inappropriate site locations for assumed similar wind speeds. Often "regional" wind speeds are cited on generic drawings without considering site-specific factors such as shielding or topography etc. These structures are presumed to apply anywhere in a region, say anywhere in Melbourne, when plainly an exposed beachfront location will suffer more severe winds than say a well shielded school courtyard location. Either one will be significantly over-designed, or the other significantly under-designed.

Better and more specific engineering and knowledge of the suitability of designs that are to be extend to different applications is needed.

- **Obsolete codes**

Another remnant of a bygone era is the misuse and inaccurate citing of wind speed criteria. Change in the wind code in 2002 (AS/NZS 1170.2) meant that the use of a permissible stress based on AS1170.2 – 1989 was no longer applicable. This obsolete code is still cited today. The citing of wind data using terms such as W41 etc is misleading, and the Building Code of Australia does not permit the use of the obsolete code with the new AS4100 steel structures code etc. Shade structures must be designed for the site specific Ultimate Strength Limit State design wind speed and for the pressure coefficient applicable to the fabric surface.

- **Irrelevant codes**

In addition to this, the publication of AS 4055– Wind Loads for Housing in 1992 has frequently been used by design engineers and cited on shade providers documentation, and surprisingly, accepted by some building surveyors. This code is specific to housing and is NOT relevant to shade structures

and should not be used. The citing of wind data using these terms such as N2, N3, C2 is irrelevant if the structure is not designed to this code, and AS 4055 does NOT give pressure coefficients for open structures such as shade structures. If a 'generic' design is to be truly relevant for multiple sites, then the Ultimate Limit State design Wind Speed can be given, and an engineer should assess the site location, region, terrain, wind direction, topography and shielding to ascertain the design wind speed.

- Limited design criteria

Given the correct wind speed, there are limited wind pressure coefficients that engineers can access that may apply to a structure. AS/NZS 1170.2 has included the wind pressure coefficients for a typical hypar shade sail, but even this is limited to specific geometries, and does NOT include allowances for porosity. The engineer is forced to make comparative assessments of multiple similar shapes to estimate a wind pressure coefficient, or try to access data from research and papers from overseas professional and technical journals, if and where they exist. These are not usually readily available to the engineer. This problem is exacerbated when trying to design a large non-regular complex surface.

More work needs to be done to make as much existing information accessible to the industry, and extend this work to make available new data as needed.

Examples of additional work that needs to be undertaken are:

- Testing to develop a database of more applicable pressure coefficients for a broader range of surface shapes, and made available to the industry,
- Provide suitable pressure coefficients for both PVC and shade cloth.
- Analyse and provide design data for open weave shade fabric drag coefficients and allowance for the effect of porosity on wind load coefficients for engineering design,

We need to lobby the Standards Association of Australia to extend their work in these areas so as to provide a more uniform and cohesive design approach throughout the industry.

The above choices present themselves as a problem and a challenge for shade companies, especially those undertaking small to medium sized projects on restricted budgets with no "in-house" engineer. We can't afford or justify the costs of a large specialist engineering firm with large fees, nor can we afford to use non-specialist engineers who don't have the knowledge or tools to properly engineer these structures. So how do we address this?

### Growing the knowledge, understanding and technology "in-house"

In the past, companies tackling the small to medium sized fabric shade structures may be forgiven for thinking that engineering services are an adjunct to the design-installation process. However engineering is an essential and integral aspect of good design, and the even the smaller designer or fabricator needs to play an active roll in the engineering process.

By bringing the right technology and tools in-house, we quickly learn a great deal more about the behaviour and loading on every aspect of the structure, including how prestress and form effects shape, dynamic behaviour, reactions of membranes on structural systems, cable requirements etc. This "in-house technology" then allows us to work co-operatively and in partnership with our small local engineer to produce better results by feeding essential information back to the design engineer.

It cannot be overstated that proper engineering is paramount and fundamental to ensuring not only a safe and structurally sound product, but it is also essential in ensuring that the fabric is able to perform to its optimum design, maintain tension and rigidity under load, and maintain shape and form in service for the duration of its life.

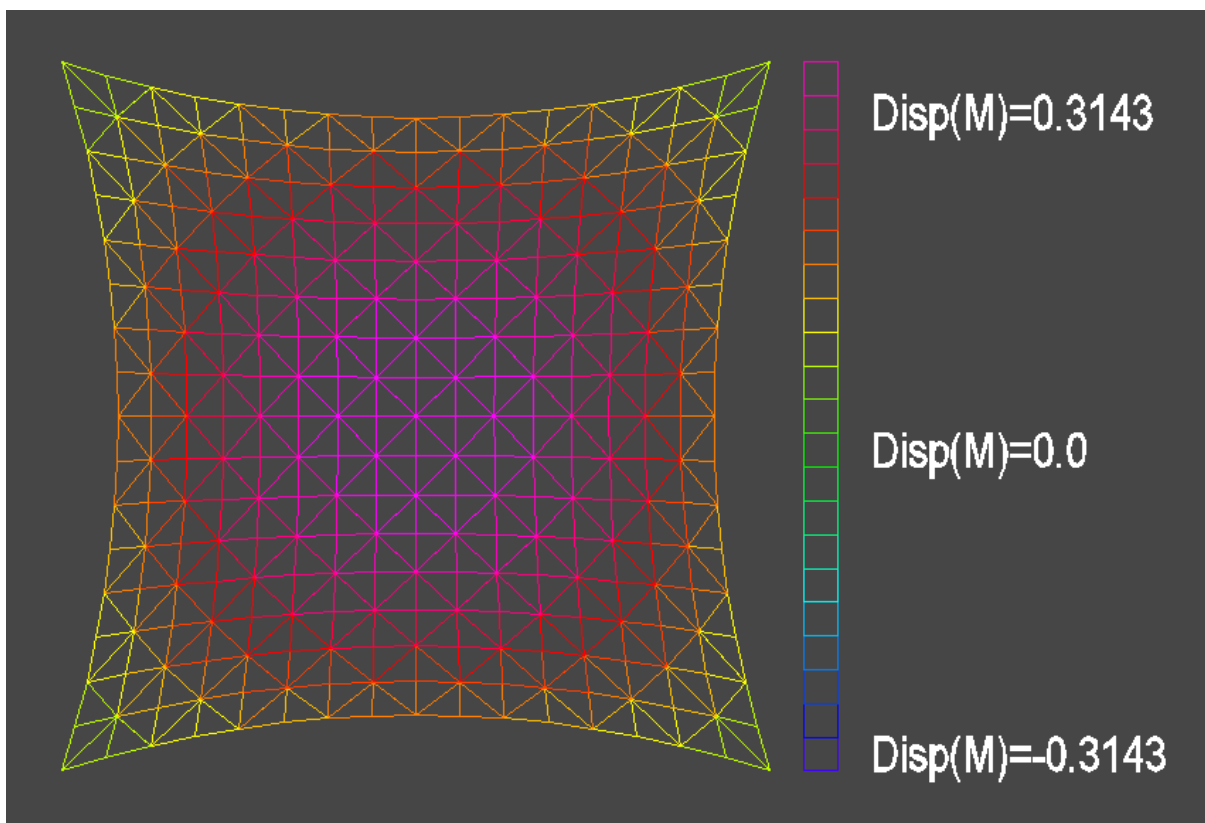
## A demonstration of the power of simple software

Up until now, design of fabric structures has been a highly specialised field requiring engineers with experience, knowledge of the behaviour and performance of tension membranes and their supporting cables and fittings, shape configurations, stress points, pre-stress requirements etc, and a good data bank of information and design parameters gleaned from others or from overseas studies. Finally, the specialist engineer needs a comprehensive suite of specialist software to analyse, model and pattern the fabric or membrane structure.

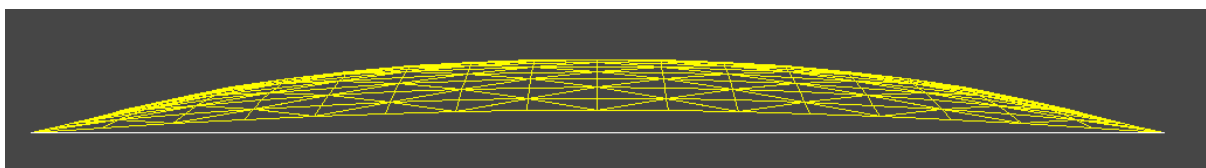
We believe that making these systems, processes and tools available and accessible to the moderate sized shade structure supplier will enable them to confidently work in partnership with their consulting engineer to produce good designs.

MPanel FEA by Meliar Design, UK is a good example of a simple, cost effective yet very powerful product which will help to achieve this goal.

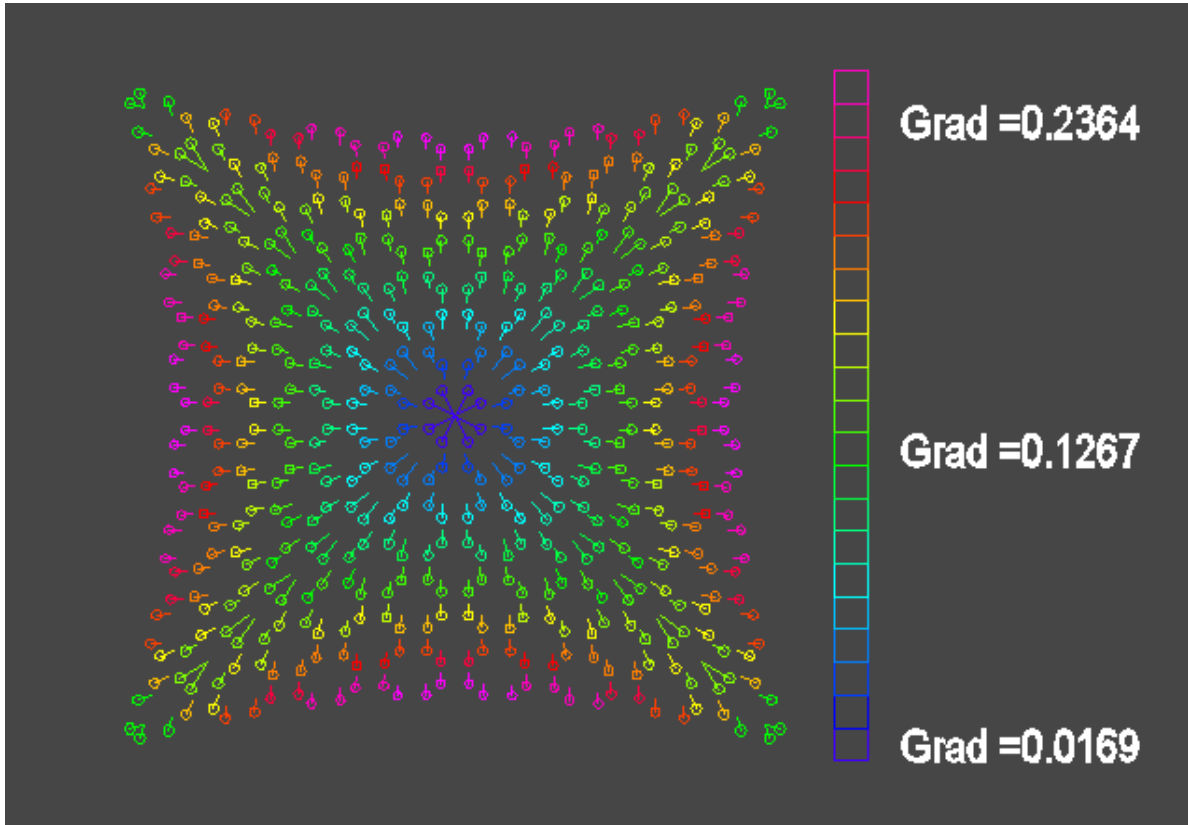
The following are screen snapshots of a simple hypar shade sail analysed using MPanel FEA.



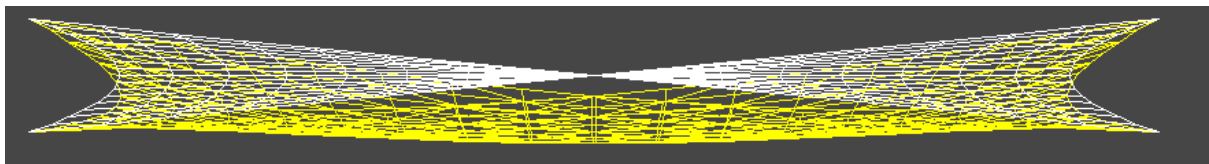
FEA analysis shows displacement magnitude of flat hypar under wind load.



FEA analysis showing an elevation of the displaced form in yellow.

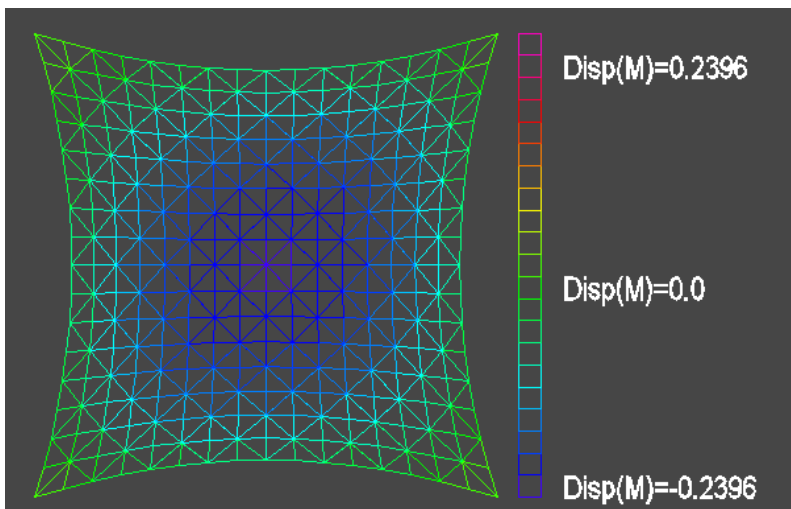


This is the same shade sail under positive (downward) pressure showing the gradient of the displaced membrane. The arrows pointing inward clearly show a sail which will “pond”.



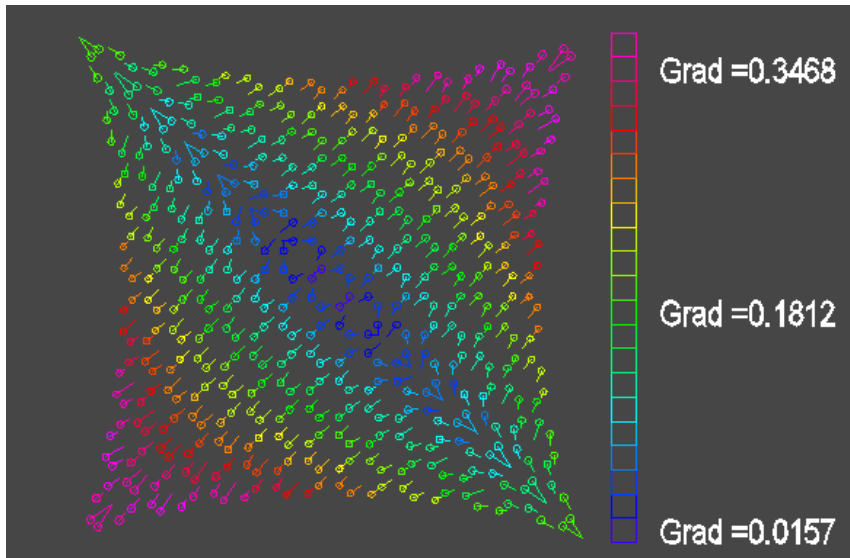
The above image now shows same membrane with 10% of span (500mm over 5m) height variation between poles. This shows less displacement but still indicated a tendency to pond.

It should be noted that it is not unusual to see many flat or near flat or “planar” shade cloth and PVC membrane structures.

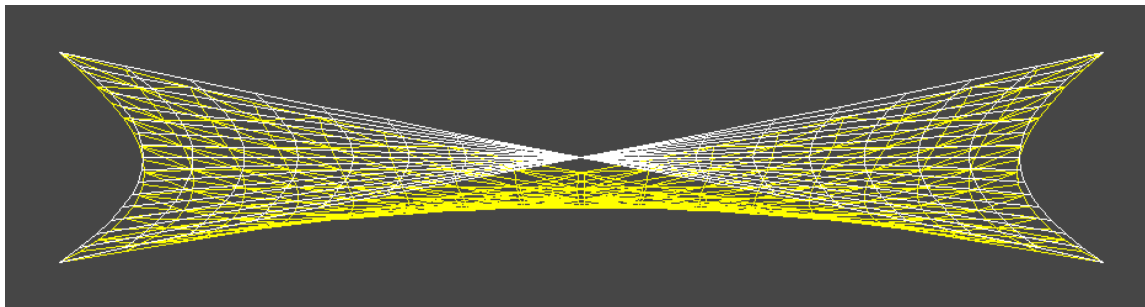


These screenshots show the MPanel FEA analysis for the same membrane with a 20% of span, (1m over 5m) height variation between poles.

Notice the reduced magnitude of displacement.



These gradient arrows clearly show the “ridging” or desired anticlastic shape maintained under load, preventing ponding.



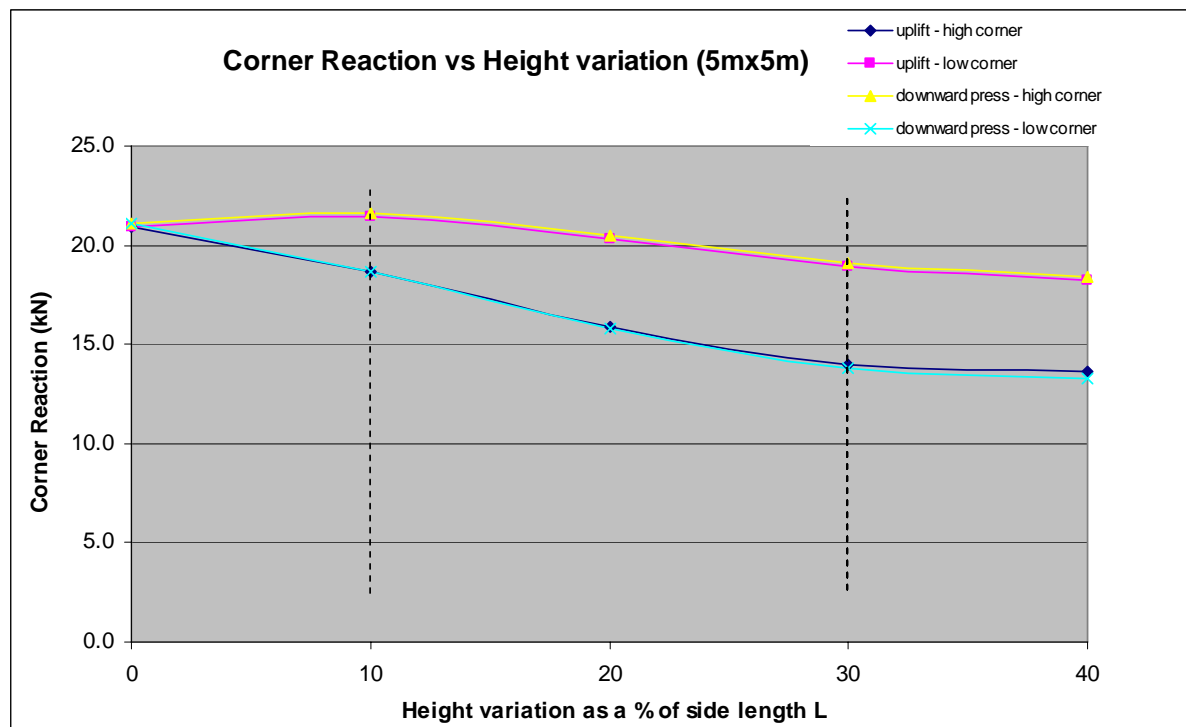
Side elevation of the same membrane showing displacement under load.

An analysis like this would have benefited the designers of this membrane structure:



To further illustrate the potential of using MPanel FEA “in-house”, one can quickly and simply run a set of possible scenarios, either for a specific job under consideration and still in the design phase, (ie – while size, shape and final geometries are still being considered), or to use it as a “learning tool” to better appreciate the dynamics of how membrane structures perform under different geometries and load configurations.

The following is a simple illustration.

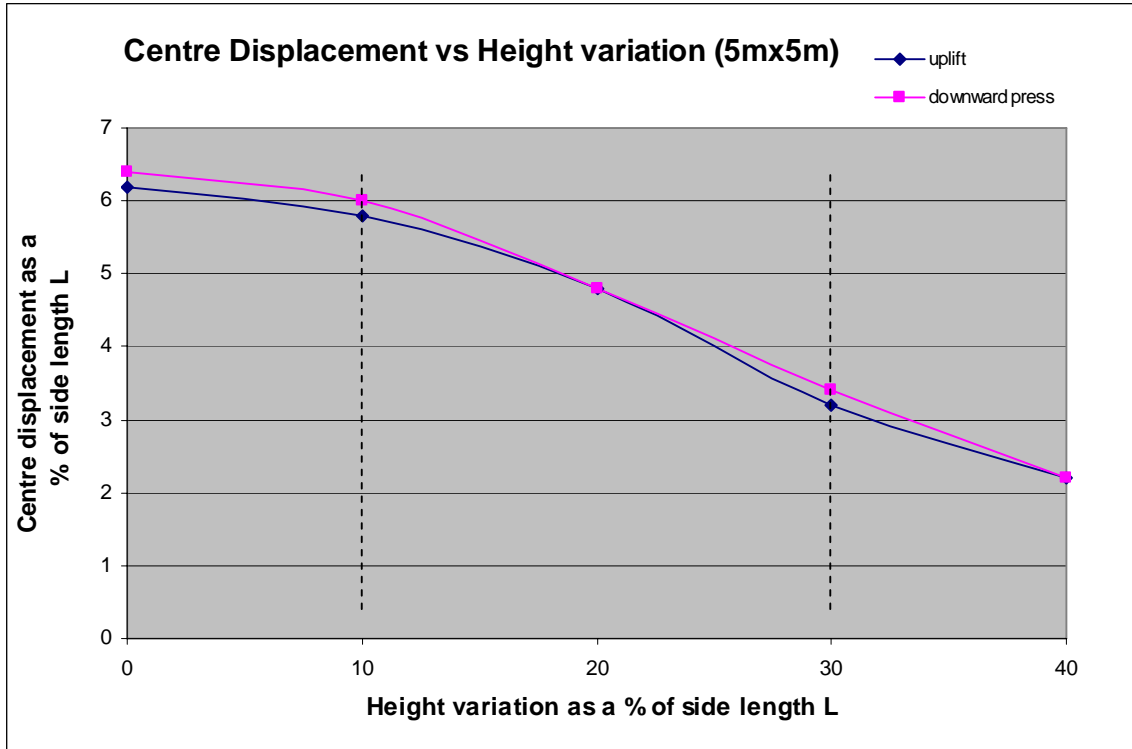


The graph above shows the results of a 5mx5m hypar under both an upward and downward uniform pressure of 0.3kPa for various degrees of height variation. The reactions are taken from MPanel FEA analysis.

Notice that the graph tends to indicate a slightly better performance for a flat sheet (0% twist). Though not recommended, this is due to the flat sheet distorting into an inflated shape with both the warp and weft going into tension and absorbing the applied load.

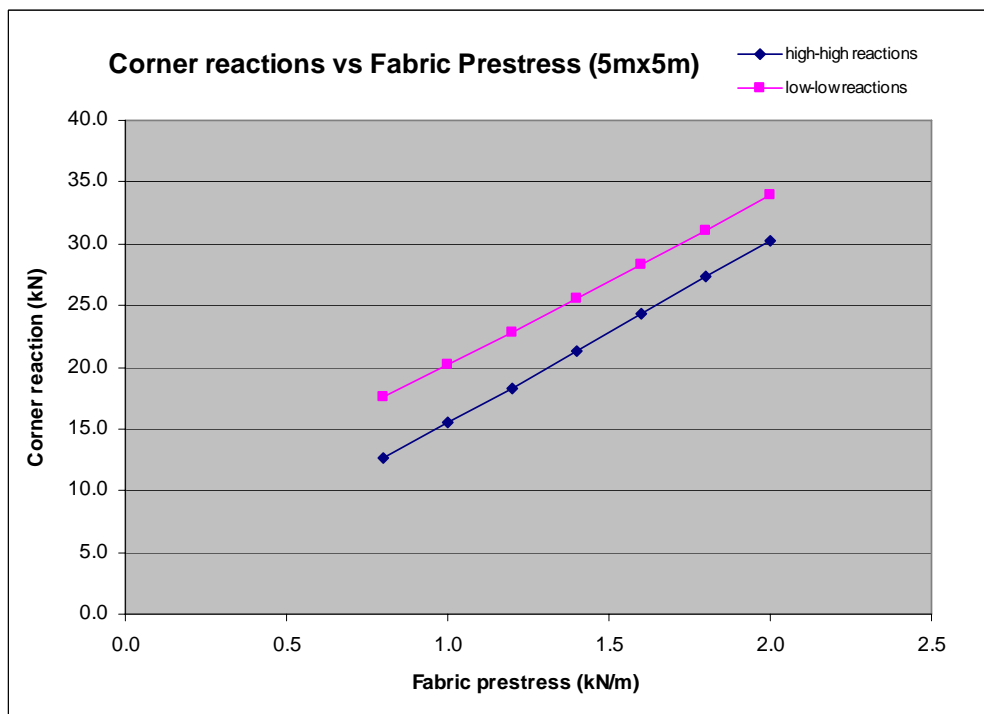
These results aid in the understanding of how height variation or “twist” in the hypar membrane affects reaction forces resisted by the supporting structure. They can also be used to assist the engineer determine realistic reactions for designing the support structures, however it should be noted that the designer should consult with the engineer when determining appropriate loads to apply when running the software, as nominating design wind speeds and wind load coefficients are the responsibility of the engineer.

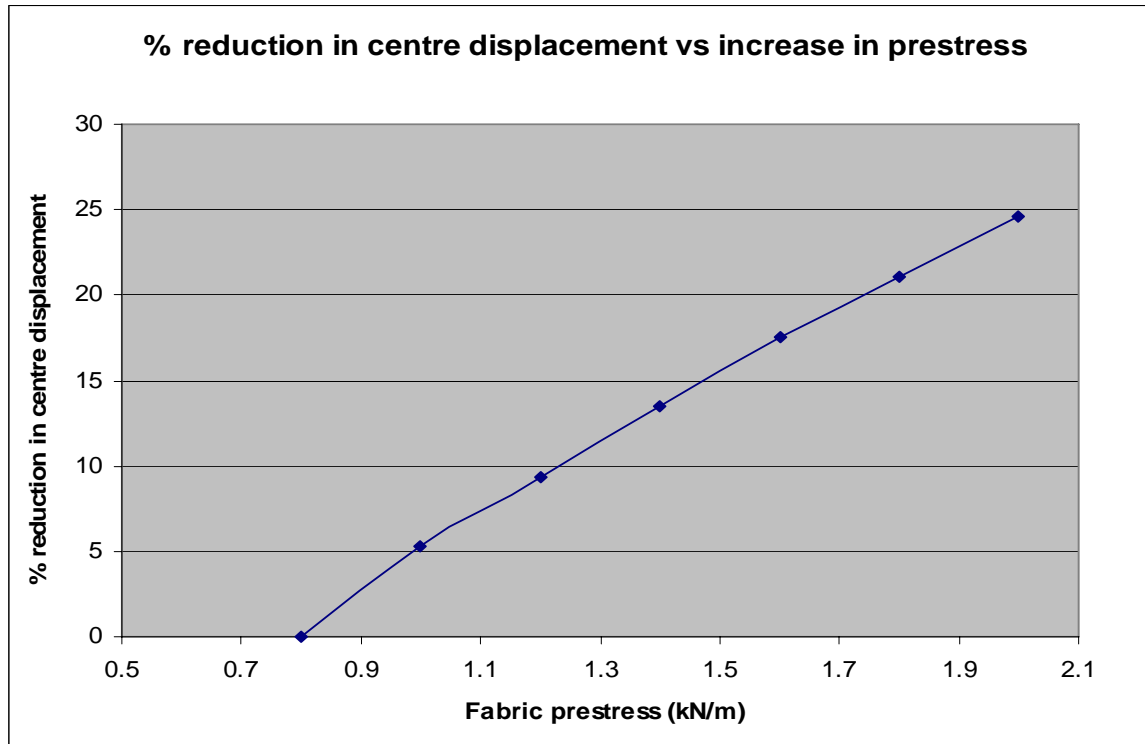
As a matter of interest, the dotted lines in the graph above represents the upper and lower limits of the geometries for hypar wind load coefficients as nominated by AS1170.2, section D7. This should not however deter designers from exploring geometries outside this limit, and we would urge more work be undertaken to provide a broader range of design coefficients for the industry.



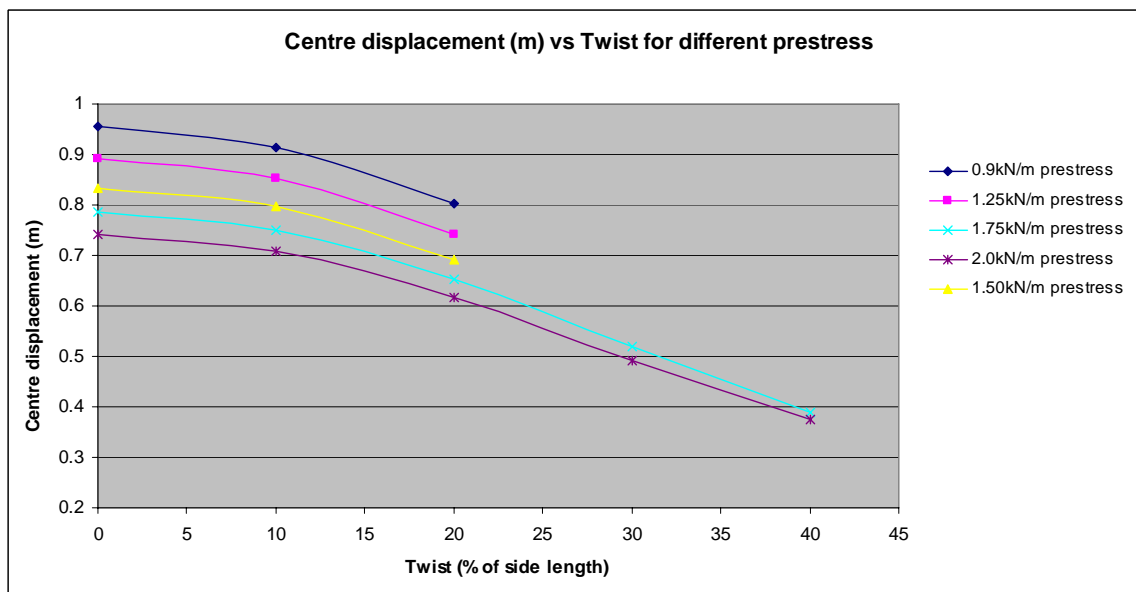
This graph shows the degree of membrane displacement at the centre for different degrees of height variation. Displacement is shown as a % of side length only as an illustration and varies with geometry, size and edge prestress, however it clearly shown the importance of height variation or “twist” in ensuring membrane rigidity. It should also be stressed that this graph alone does not show potential for ponding.

A further illustration of the potential of MPanel is considering cable edge prestress. As mentioned previously, designing membrane structures is an iterative process where several variables need to be considered and the most efficient and balanced design is realised simultaneously.





Apart from support reaction forces, membrane displacements vs. prestress can be analysed at the same time. The above graph illustrates the % reduction in membrane displacement with increased prestress.



The above graph shows centre displacement vs. height variation or twist for different degrees of fabric prestress.

One of the problems designing membrane structures, particularly shade sails, is the propensity for them to relax and lose their prestress under load if insufficient shape, form and prestress is given them. (In addition to creep and elongating with age). This causes fatigue on fittings and chafing of the fabric due to heavy cyclic loading in high winds, accelerating the deterioration of the fabric.

MPanel FEA can be used to check that tension in the fabric does not fall below zero, ie. The fabric loses its tension in one diagonal direction altogether and “theoretically” goes into compression.

Insufficient twists and prestress allows an excess in relaxation of the fibres in one direction, while increasing in the other. (Though not ideal, a “flat” membrane would potentially have equal stressing in both diagonal directions.)

This would not necessarily be obvious or apparent to either the engineer or designer without such tools and the desire to explore and analyse these structures.

The above situation needs to be avoided and a careful balancing of all these factors, allowing a “give and take” of geometry, height variation, prestress, support reactions etc, to optimise design can easily be achieved with the use of such technology.

## A brief comment on regulations

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Many shade merchants may fear the loss of competitiveness if they increase their overheads by embracing these technologies and bearing the costs for engineering.

By comparison, the housing market over the last two decades has seen a substantial increase in overhead costs as builders have had to introduce mandatory safety measures and comply with new building regulation including undertaking site surveys, soil tests, site fencing, roof scaffolding, more engineering and many others. However, these regulations have not only improved the quality and safety of the product and the industry, but all builders have found themselves on a “level playing field” and there aren’t, (or shouldn’t be) those who do and those who don’t undertake these measures.

By embracing the need for standardised design and safety measures, whether imposed externally, (by government regulation), or developed internally, (as a responsible self-regulated industry), we can eliminate many of the problems cited above.

## Conclusion...

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Fabric structure engineering is a specialised field; however it need not be exclusive.

By providing engineers and designers with the right tools and resources, we can empower the industry as a whole to undertake a new generation of successful fabric structures.

There’s no reason why a well executed \$5,000 structure can’t be “spectacular” if properly and thoughtfully designed. We don’t all have to produce a “Millennium Dome” to be proud and satisfied in what we’ve achieved or produced.

Finally, software alone is not the complete solution and designers must work together with their engineers and must employ good and well proven design techniques to ensure that they and the shade industry as a whole is seen as a vibrant, sustainable and preferred system of shade solutions for the 21<sup>st</sup> century.