

Commentary on the existing Shade Structures Policy BAC 2005/1 and the need for a new policy

INTRODUCTION

This policy was first introduced in November 1996 as BAC/P1 and later revised in April 2005 and re-adopted unchanged in July 2007. The industry finds the policy regarding concessions difficult to understand and apply¹. This results in a variety of interpretations, some of which have resulted in premature failure of these structures at regional wind speeds less than 41m/s. It is therefore timely to review the policy in light of a modern design philosophy, which is based on risk and reliability theory. In addition to 'permanent' shade structures, the NT has seen the increasing use of temporary (event) type fabric covered structures. The current policy does not address these temporary structures.

The analysis and design of small shade structures, including impervious sails, is not straightforward. Even amongst the experts in this field there is considerable variation in the nodal forces and equilibrium shape derived for these fabric structures under load. Simplified methods of analysis are often adopted that are based on statics and linear elastic behaviour. These methods are highly questionable².

Three industry-accepted methods for analysis of tensile membrane structures are well documented in the European Tensinet³ publications. These methods generally apply to PVC coated polyester fabrics (impervious) and more advanced materials such as Kevlar and fibreglass fabrics. Use of these methods with shade cloth materials requires care in estimating the warp and weft properties in order to achieve convergence. At least one specialist software manufacturer claims that none of the software produces credible answers for small structures and that engineering judgement is required in interpreting the results⁴.

THE EXISTING POLICY

The general requirements and the Part 4 siting concessions of BAC 2005/1 are in the main, satisfactory. The Lightweight Structures Association of Australasia has released guidelines⁵ that should be referenced by the new policy. The second sentence in paragraph 5 of the general requirements should be removed as in certain circumstances it is not conservative⁶. It is also misleading that this value (± 0.17) can be used for certain shaped structures, including attached canopies and it fails to take into account the significant drag forces on deformed shape shade cloth materials. The value was suggested to provide guidance to designers on what net pressure coefficient to use as a minimum value. It appears to have become the de-facto value to use, because it is difficult to find research data. Designers and manufacturers tend to keep these net pressure coefficients close to their chests and that is in part the reason for the scarcity of information. Designers should make their own assessments of pressure coefficients based on published values from journals and other technical publications. The BAC should not stipulate a value that is not universally applicable and could be misused.

1. Conversation between Russell / Taylor (Aerosail)

2. Conversation between Russell/Kneen (LSAA)

3. Tensinet - European Design Guide for Tensile Surface Structures - ed. Forster & Mollaert

4. Conversation Russell/Taylor/ Gerry Danza

5. LSAA - Guidelines for Design, Fabrication and Installation of Tension Membrane and Shade Structures (May 2012)

6. Mean Wind Loads on Porous Canopy Roofs - Letchford et al (Journal of Wind Engineering and Industrial Aerodynamics 84 - 2000)

PART 1 - Concessions for non-cyclonic areas.

Use of $V_u = 41\text{m/s}$ as a basic ultimate wind speed refers to the 1989 version of the wind code AS 1170.2. That Standard adopted 50m/s and 60m/s (ultimate limit state) for regions A and B respectively for housing. Housing provides shelter for people in extreme winds whereas shade structures do not. As such it was reasonable to use a lesser value where the consequences of failure were not as severe and failure was not likely to endanger life. For housing, the accepted risk of exceedence in a fifty year life is 10% (importance level 2). So, it would appear logical to design shade structures for a greater risk of exceedence than 10%, say importance level 1.

The rationale for choosing 41m/s in the current BAC policy for both regions A and B is not known, but in today's standard this equates to a 100 year average recurrence interval (ARI) storm in region A and a 30 year ARI in region B. That is quite a disparity for these two non-cyclonic regions and needs to be addressed.

It is suggested that the consequences of failure of some shade structures are greater than others. For example, structures in public areas such as schools and parks should be considered differently than those in a domestic backyard. Currently this is not the case.

It is suggested that two importance levels for shade structures be considered. An importance level for private structures and an importance level for public structures. Examples of private shade structures would include those associated with class 1 and 2 buildings whereas public structures would usually be larger and located in areas such as schools and parks. The design life of private shade structures is assumed to be 10 years and 15 years for public shade structures. This is based on experience of the Darwin market. The textile fabric coverings may well need replacement several times during that period.

For Importance level 1 structures, the risk of exceedence of the design load should be in the order of 0.20 to 0.25, in accordance with Appendix F2 of AS/NZS 1170.0:2002. It is suggested that the higher value be associated with private shades and the lower value with public shade structures. These values can be related to risk of exceedence in a lifetime (assuming all years are statistically independent) using the equation $r = 1 - [1 - (1/R)]^L$ where r = risk of exceedence, R = average recurrence interval and L = lifetime in years.

Using the above data in the risk equation we have:

- Private shade structures ARI = 35 years (with $r = 0.25$, $L = 10$)
- Public shade structures ARI = 67 years (with $r = 0.20$, $L = 15$)

The corresponding Regional Wind Speeds from Table 3.1 of AS/NZS 1170.2:2011 would be:

TABLE 1. (V_R - m/s)	REGION A	REGION B
Private Shade Structures	38	42
Public Shade Structures	40	46

This represents about 47% difference between the maximum and minimum wind **pressure** values which has rather more logic to it than the blanket 41 m/s concession for both regions.

PART 2 - Concessions for cyclonic areas

It is considered important for owners to be made aware of the concessions for shade structures and not to expect performance from these structures that is unreasonable and inconsistent with the degradation of the materials, stitching and fatigue of the connectors over time.

Whilst the warranties on fabric and stitching are much better nowadays, the choice of materials and methods for use in construction still varies markedly between manufacturers. These concessions exist because they are relatively cheap structures to replace, they have a short life span, they present little danger to human life in the event of failure and to design for full wind loading would be cost prohibitive.

The removal of the textile fabric in the event of a cyclone warning is sound practice but in reality it is rarely done. Owners know they run the risk of tearing the fabric or damaging the structure but the failure mode is generally ductile and does not cause consequential damage if rigging is connected correctly.

Whilst it is a rare occurrence for fabric to be removed in the event of a cyclone warning in either commercial or private situations, there have been some notable exceptions. There are several installations that have a "feasible system for removing the fabric" which involves a carriage on the kingpost. Perhaps there is some concession to wind loading that could be made in those circumstances provided it can be assured that the dismantling will be carried out. In any case, a lower limit $V_{des\theta} = 30\text{m/s}$ is suggested for these structures.

The vast majority of small shade structures however are hypars or co-planar shades without such provisions. Individuals and businesses have a lot more to concern themselves with other cyclone preparations than to remove and store shade fabric safely. Many are prepared to lose the fabric and claim it on insurance. Most people **assume** the fabric will fail before it damages their building or the footings and columns. Most designers protect those expensive elements by installing at least one "weak-link" designed to fail before the footings and columns.

Based on the foregoing comments, it is proposed to delete the fabric to remain / fabric to be removed distinctions in the current policy. This clause has created many low wind speed designs for large fabric structures where it is not feasible to remove the fabric during breezes of 15 to 20 knots that often prevail at the time of a cyclone warning. The NTG have recognised this and have their own policy to design school and large structures with no concessions (and currently based on IL 2 with 50 years life). Given the short lifespan and low importance of these structures, it can be argued that is an unreasonable approach.

Using the same risk and reliability approach as in the preceding section, the following table of regional wind speeds in cyclonic areas results:

TABLE 2. (V_R - m/s)	REGION C	REGION D
Private Shade Structures	49	56
Public Shade Structures	56	69

At this point it is worth presenting some examples to demonstrate what these regional wind speeds might equate to for a few shade structures.

Example 1 - Establish the design wind speed for a 500m² shadecloth pyramid roof of average height 5m to be used for a prison facility in Darwin in a terrain category 2.5 roughness environment. Assume shielding and topography multipliers are unity.

$V_R = 56\text{m/s}$ (public area structure in region C from Table 2)

$M_d = 0.95$ (major framing elements eg. columns, footings)

$M_{zcat} = 0.87$ (from table 4.1 of AS/NZS 1170.2:2011 Amdt 2)

$M_s = M_t = 1.0$ (as given)

$V_{des\theta} = 56 \times 0.95 \times 0.87 = 46\text{m/s}$

$p_{zu} = 1.29 C_{fig}$ kPa (where C_{fig} includes an area allowance K_a and porosity factor K_p)

Example 2 - Establish the design wind speed for a 30m² PVC coated polyester (impervious) hypar in suburban Malak (Darwin TC 3) with average height of 4m

$V_R = 49\text{m/s}$ (private area structure from Table 2)

$M_d = 0.95$ (major framing elements eg. columns, footings)

$M_{zcat} = 0.83$ (from table 4.1 of AS/NZS 1170.2:2011 Amdt 2)

$M_s = 0.85$ ($s = 4.5$ refer AWES Commentary)

$M_t = 1.0$

$V_{des\theta} = 49 \times 0.95 \times 0.83 \times 0.85 = 33\text{m/s}$

$p_{zu} = 0.65 C_{fig}$ kPa (where C_{fig} includes an area allowance K_a)

As can be seen from the above two examples, the design wind speeds are achievable and are based on a rational approach that takes into account importance, location, probability of exceedence over the life of the structure and economic feasibility.

TEMPORARY (EVENT) STRUCTURES

Background

Temporary structures for use at public events are commonplace in the Northern Territory because of our long and climate friendly dry season in the Top End. They are also quite popular in the Alice Springs region, where the climate is conducive to outdoor events. It remains that most public events that utilise these temporary structures do not obtain building approval or engineers section 40 certification. The requirement for doing so is very 'hit and miss' and is often based on what that might cost. Event Managers are often asked by the suppliers whether they require certification and most often they decline. It is therefore imperative that either the NCC or a National Code of Practice address these issues.

All temporary structures are susceptible to wind loading, which is most often the governing criterion. These structures include aluminium portal frame marquees, circus tents, temporary grandstands, bleachers, screened scaffold platforms, screened temporary fencing, event signage, overpasses, temporary ablutions blocks, viewing platforms, winners rostrums, temporary shadecloth structures on steel frames and even container technology.

Aluminium portal frame structures in particular are susceptible to wind loading and most have been designed for around 80 kph (PSD), fully enclosed with low or zero internal pressures. This is generally because they are of European origin and it is cost prohibitive and unnecessary to do otherwise in that low wind speed environment. Snow loading is often a governing criteria for most of these structures. However in Australia, and particularly in the NT, clients tend to want three sides enclosed, or partial walls which result in much increased loads on the structure and its anchorage system. In my experience, it is useless to advise them that they cannot have such configurations, much the same as it is useless to tell teams not to remove the longitudinal bracing from these structures. These matters have to be "managed" on site by trained personnel who are aware of the implications and are ready to intervene by de-skinning or closing up. It is one very important reason for rostered staff during events, with handheld anemometers and a good link to the Met Bureau radar.

In the NT, these portal frame structures are erected without compliance to either AS/NZS 1170.2 or AS/NZS 1170.0 Appendix F. Until amendment 5 of 1170.0 (September 2011), the requirement for temporary structures was **unachievable** in cyclonic areas, as it required a V_{200} wind speed of 64m/s (in region C). This was pointed out to the code committee on many occasions previously, but there was a reluctance to have it changed. As it stands now, the Standard still requires L=25 years, V_{200} for temporary structures in cyclone season. The design life of 25 years is governed by the wording of paragraph 1 in F3 of 1170.0. It could be argued that there is no danger to human life if standing orders are to cancel the event and evacuate in the event of extreme winds. Australian circuses have such protocols (along with shielding and additional tie down), however we have witnessed concert promoters (in the USA) ignoring those warnings with loss of life resulting.

Local practitioners when dealing with temporary structures have used a value of 30m/s for some time now, but there was no expert substantiation for that and certainly no support from Standards Australia. A number of local practitioners independently analysed the past 50 years of wind data for Darwin Airport and extracted those values associated with tropical cyclones (for which there is sufficient warning to de-skin). It was decided that 30m/s was an appropriate **design** wind speed for temporary structures (erected for a week or so) in the NT.

In 2006, I commissioned Dr Holmes (on behalf of Total Event Services) to undertake a "Special Study" in accordance with AS/NZS 1170.0 Appendix A to establish a suitable wind speed for temporary structures in Darwin. Partly as a result of that study and his work on HB 212 - 2002, amendment 5 to AS/NZS 1170.0 was created. Without the Holmes study, it would be difficult and costly to meet the wind loading requirements of amendment 5. The paper has not been published (to my knowledge) and remains the property of Dr Holmes and Total Event Services. The NTG are aware of this paper by Holmes and have hardcopy.

Wind Loads for Temporary Structures - after Wang & Pham (AJSE Vol12 No2 - 2012)

Regardless of whether or not one agrees with the philosophy behind this report (ignoring design life and making comparisons on the basis of region A only), the results are acceptable to end users in the NT for short duration events of 1 week or less.

They may be less acceptable to users in Region D, who may still have to operate outside the Standard in order to conduct outdoor events. Alternatively, they could seek a "Special Study" in accordance with Appendix A of AS/NZS 1170.0 and hope that affords them some protection in law, should that be required.

Applying the Wang & Pham criteria to the Rugby Sevens and V8 supercar events in the NT for example, we have:

Example 1.

- Importance level 2 structures (<300 pax per structure - Rugby Sevens **during cyclone season**)
- $V_{500} = 69.3\text{m/s}$ (Note that $R=500$ and hence $F_c = 1.05$)
- $V_{R,s} = 69.3 \times 0.55 = 38.1\text{ m/s}$ (approx 1week event duration)
- $M_{z,cat} = 0.91$
- $M_s = M_t = 1.0$
- $M_d = 0.95$
- $V_{des\theta} = 38.1 \times 0.91 \times 0.95 = 33\text{m/s}$ (for footings and major framing elements)

Note that this is an event (along with many others) that occurs during the cyclone season from November to April, a period of 6 months. Such events are not going to be cancelled by the NT Government or Tourism Authority just because event structures cannot meet the current wind loading requirements. They will continue to operate outside of the law and run such risks, particularly if they can shed that risk to others. It is my believe that note 4 under table F2 of 1170.0 is a compromise between John Holmes and Richard Weller. Lam Pham now appears to be on-side as his results above clearly show. The fact is that the NT has reasonable advanced warning of cyclones (approximately 4 days) and events such as this would be cancelled days before patrons begin to enter the venue. There remains sufficient time to de-skin structures and remove temporary signage so that it does not become flying debris. The real concern is for wet season tropical thunderstorms and their associated wind gusts which reach up to 30m/s, for which there is only one hours warning. In that respect, we are not much different to our Region A cousins.

Based on structural analysis and full scale testing of the portal frame knee joints at CDU, it is possible to achieve this wind speed on some **standard** HTS Röder, Interlock and Veldeman structures. It should be noted that some suppliers do not have sufficient stock in a small place like the NT to be able to use a larger profile on a small span and many clients won't pay for that in any case.

Example 2.

- Importance level 2 structures (<300 pax per structure - V8 Supercars **non- cyclone season**)
- $V_{500} = 45\text{m/s}$ (using region A wind loads within region C non-cyclonic season)
- $V_{R,s} = 45 \times 0.75 = 33.8 \text{ m/s}$ (<1week event duration)
- $M_{z,\text{cat}} = 0.91$
- $M_s = M_t = 1.0$
- $M_d = 1.0$ (Region A1-A7 value any direction)
- $V_{\text{des}\theta} = 33.8 \times 0.91 = 31\text{m/s}$ (for footings and major framing elements)

This design wind speed can be achieved by standard structures **provided** they are fully open or fully enclosed and have no potential dominant openings. Currently, designers must use note 4 under table F2 of 1170.0 which allows them to design for Region A with a design life of 25 years (human safety), IL 2 with a 1:200 annual probability of exceedence. This results in $V_{200} = 43\text{m/s}$, $M_{z,\text{cat}} = 0.91$, $M_d = 1.0$ and $V_{\text{des}\theta} = 39\text{m/s}$.

Most **standard** temporary structures will still struggle to meet this requirement and hence the Holmes report is invaluable to designers of temporary structures in Darwin. It is of note that for temporary structures in Region A4 (Alice Springs) the same value applies (viz. 39m/s) as no special study exists there. That results in an anomaly whereby Darwin temporary structures could be designed for a lower wind speed than those in Alice Springs. Perhaps this is not such an unusual matter as this was noted in the Holmes report of 2006.

The Wang and Pham paper is therefore of considerable value to the temporary (event) structures industry in both non-cyclonic and cyclonic regions and they are to be commended for presenting it at the ASEC 2012 conference and having it published in the AJSE Vol 12 No 2. The reduction factors derived in that paper have been applied for temporary structures in the NT under the proposed new policy. Exposure durations of 1 week, 1 month and 6 months are nominated and would apply to the whole of the NT. The values are not meant to over-rule the results of any "Special Studies" in accordance with Appendix A of AS/NZS 1170.0:2002, however they are more universally applicable for regions beyond the extent of any special study.

Non-Cyclonic Extreme Wind Speeds for Darwin - (Holmes 2006)

As previously mentioned this study came about because I was concerned that practitioners were operating outside of the Standards without expert opinion on whether their assumptions could be justified. A copy of the unpublished Holmes study has been provided to the NTG, but it remains commercial in confidence. The study applies to Darwin only and should not be extrapolated beyond there. Holmes has however drawn parallels to the results for Darwin and what he found in HB 212 - 2002 "Design Wind Speeds for the Asia-Pacific Region".

Of particular significance, Holmes found that the "non-cyclonic wind speeds in Darwin are somewhat lower than those prescribed for Region A" in the Standard and further he also found that 75% of the wind gusts greater than 15m/s occurred during the wet season (cyclone season) and concluded that the **non-cyclonic** gust wind speed for Darwin could be defined by $V_R = 58 - 38R^{-0.1}$ (including the wet season).

For temporary structures whose design working life might equate to 5 years say (total time the structure is exposed), and whose life risk of exceedence is set to 0.10, then $V_R = 32\text{m/s}$. Whilst this value could be further reduced for terrain/height, shielding and direction multipliers, the minimum design wind speed $V_{\text{des}\theta}$ should not be reduced below 30m/s in accordance with section 2.3 of the Standard. Hence the current practice of using a design wind speed of 30m/s for temporary (event) structures **in Darwin** appears to be sound.

Holmes' study (region C) shows a variance of 42% in design load from the analysis of Wang and Pham, which can be accounted for by the fact that W&P used cyclonic wind data in their analysis. To suggest that the temporary (event) structures should consider data with cyclonic values as their basis is foolhardy, unless the restriction of "outside of cyclone season" is lifted.

THE PROPOSED NEW POLICY

It is proposed that a new policy be adopted after circulation to and comment by the industry. The new policy should consider a rational approach rather than a "one size fits all" concession policy. The new policy should consider that:

1. different classes of shade structures exist within the NT along with three distinct wind regions. Some structures are more important than others.
2. the LSAA has provided recent guidelines that both designers, fabricators and erectors should be cognisant of.
3. that a blanket 41m/s concession has little justification as does nominating a pressure coefficient of ± 0.17
4. the design life of some public structures exceed that of other more general structures and that all shade structures have a design life (and importance) less than that of a house.
5. in general, owners do not take down their 'permanent' shade structures in the event of a cyclone warning and in many instances for larger structures using this concession it is a WHS risk to do so.
6. concessional wind loads for shade structures be based upon the AS/NZS 1170 series Standards and yield design wind speeds that are both achievable and appropriate for the economic risk.
7. there is an increasing use of temporary (event) structures for which there is no applicable Australian Standard for wind design. Either a National Code of Practice for Temporary Structures or new provisions to the NCC are in the planning stages and this unregulated industry needs guidance now.
8. the owner needs to take some responsibility for acceptance of concessionary wind loads when they purchase a structure.