A historical appraisal of structural engineering associated with Australian Antarctic buildings

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ABSTRACT
Australia has three permanent bases on the Antarctic continent that are occupied year round: Casey, Davis and Mawson stations. Adequate shelter is essential for survival, particularly for those who are isolated for 9 months each year during the winter period. Buildings must be engineered to withstand the extreme conditions that the Antarctic climate can produce.

The structural design of Antarctic buildings needs to address more than just the severe climatic conditions. The extreme variation between the internal and external temperature along with a need to address the annual freeze/thaw of the permafrost; particularly its impact on the building foundations is required. The buildings have evolved over the years since the establishment of Australia's first station at Mawson in 1954. The initial buildings were based on a series of prefabricated huts. The station rebuilding program that commenced in the late 1970s addressed many of the unresolved constraints that faced the designers of initial buildings, and resulted in the distinctive AANBUS buildings of today. More recently, a large fibre composite building was commissioned at Davis to provide living facilities for up to 120 expeditioners. This building uses the inherent strength within fibre composite panels to minimise the steel framing requirements.

KEYWORDS
Antarctic; Australian; AANBUS; Buildings; Pre-fabricated.

BACKGROUND
Antarctica is a continent of extremes. It is the coldest place on earth with mean annual temperature on the Antarctic coast being minus 17°C. The coldest ground temperature recorded on earth was minus 89.2°C at Russia's inland Vostok station in 1983. It also is the continent with the highest average elevation (2300m), which serves to exacerbate the cold. The very cold air also results in an extremely dry atmosphere. Despite having an estimated 70 per cent of the world's fresh water reserves locked up in its ice sheet, it is the driest continent on earth, with less moisture falling on it than most of the world's hottest deserts (Bowden, 1997). Antarctica is also the windiest continent, primarily as a result of its domed shape. Air at the centre flows outward to lower elevations (just as water flows down hill), and accelerates as it reaches the steeper slopes near the coast (DH&C – 1980). A wind gust of 320kph (90m/s) was recorded at the French Dumont d'Urville station in July 1972.

The main challenges for engineers associated with Antarctic buildings are:

1. The extreme external cold creates a very large temperature differential across the external insulated cladding, inducing large stresses on the panels;
2. Design winds are that of a category five cyclone, and the debris that these winds pick up that also needs consideration; and
3. The very dry climate of Antarctic, with low snowfall and a dry atmosphere, results in desiccated building materials and creates an extreme fire risk.

INTRODUCTION

Australia established its first permanent station on the Antarctic continent at Mawson in 1954. Davis was established in 1957 for studies associated with International Geophysical Year (IGY). Two years later, Australia took over the running of Wilkes, built by the USA on the Clarke Peninsula for IGY. As Wilkes rapidly deteriorated due to snow and ice accumulation, nearby Casey station was built to replace it. Today all three stations are occupied year round, with Mawson being the longest continually occupied station in Antarctica (Incoll[1], 1991).

Australia's Antarctic stations were originally built using small, lightweight, prefabricated huts; that could be easily erected under adverse conditions. They were engineered to be erected by an unskilled workforce and without the aid of mechanical plant. These original huts were a far cry from the facilities available today on the continental stations of Mawson, Davis and Casey. The development and installation of the Australian ANtarctic BUilding System (AANBUS) by the engineers and construction teams involved in Australia's station rebuilding program during the 1980s and 1990s has become an internationally accepted benchmark in Antarctic and cold-region design. Even the most recent building designs adopt much of the approach of AANBUS, but incorporate additional 21st century innovation.

There are a number of Antarctic specific challenges that faced engineers in the early days, which still need to be addressed today:

1. Can building materials be containerised or suitably packaged to be transported across the Southern Ocean within the hold or decks of an ice strengthened ship?
2. Can these materials then be moved around and erected using only the plant, equipment and personnel at an Antarctic base, with no option for additional resources after leaving Australia ?
3. Will the building be suitable to withstand the Antarctic winter in a half-finished state, or if not, what temporary works are required to manage this?
4. After all of the above, does the building still achieve the original purpose that the structure was designed to accomplish?

IN THE BEGINNING - Heard and Macquarie Island

A station was established at the sub-Antarctic Heard Island in 1947 using two types of huts. One type was the fourteen-sided plywood sandwich panel with fibre-glass insulation, often referred to as Alaskan huts. The other type was surplus WWII Borden prefabricated hut externally lined with masonite and with no insulation. The Borden huts had been designed for the tropics with ventilation panels at the top and bottom of the wall panels (Incoll[1], 1991). The huts were typical of housing construction of the day with the external cladding nailed to the timber frame.

The first Antarctic design innovation came with the ANARE (Australian National Antarctic Research Expeditions) Mark 1 huts; which were so effectively insulated that condensation built up within them and a small ventilator was required to overcome the problem. These huts included plywood clad, isolite insulation panels fixed to an Oregon timber portal frame structure. They combined the good points of the existing plywood skin construction of the Alaskan huts, with the simple building form of the Borden huts (Smith, 1972). The key improvement of the design was that the panels became structural (load-supporting) and were fitted together using a tongue and groove approach. This made the hut easier to erect and provided a superior joint in terms of wind, grit, snow ingress and water (snow-melt) shedding. These improvements still achieved the requirements to have reliable, convenient huts that were easy to transport by boat and land in an amphibious vehicle, quick to erect by unskilled labour, and easy to maintain.

This advancement in building approach, along with the access to a suitable ice-strengthened ship, enabled Australia to establish its first station on the Antarctic continent at Mawson in 1954.

ESTABLISHING THE FIRST STATIONS - Post Tensioned Box buildings

The buildings developed for Mawson initially, and then Davis, mostly comprised of post-tensioned, load bearing insulated panels without internal framing, but needed external guys for stability. The buildings were designed in a manner that allowed most prefabrication to be undertaken prior to departure to Antarctica, then quick erection on-site. The buildings were designed to provide basic living facilities that could be rapidly completed using the ship for support. When Davis was established, the supply ship ‘Kista Dan’ started unloading materials at Davis on January 12, 1957. The ship departed for Mawson eight days later leaving behind a functional powerhouse, sleeping building, mess building and a store already in place.

The buildings were developed by adapting the standard cool room panels of the day to produce exterior insulated panels that were load supporting. The insulated panels were timber framed and filled with rigid foam bakelite insulation, and sheeted on the outside with aluminium sheet (later versions adopted plywood outer skins) and inside with either 'Masonite' hardboard or plywood. To provide the structural suitability for an Antarctic blizzard, a post-tensioned approach was adopted for the buildings. Steel threaded rods were inserted through conduits built into the panels. The post-tensioned rods ran the full length of each wall, the floor and the roof and were tensioned up by nuts at each end. The tensioning rods also compressed the rubber gaskets between the panels to provide a weather-proof seal (Smith, 1972). The buildings were constructed on railway sleepers (or local rocks at Davis, piled up) to make a level platform. A steel framework was fitted around the edge of the roof and anchored to the ground with steel guy-wires to secure the buildings during high winds.

Figure 1
Davis - Jan 1957:
The buildings were supported on timber sleepers and guyed to the ground (Photo PG Law)

Figure 2
Davis - Spring 1957: Snow drifts had rendered the main doorways obsolete, with the roof hatch the egress (Photo WRJ Dingle)

Figure 3
Installing the new Surgery at Davis, the rubber gasket (grey edge) is just visible on the panel being installed. (Photo PG Law)

The lightweight prefabricated panels forming both the internal and external wall had a number of drawbacks. The layout of the buildings resulted in considerable snow build-up and consequently water leaks during the summer snow melt. It was not possible to re-tension the rods whilst the buildings were mostly buried in snow. The saturated foam insulation then provided very little thermal resistance. The panel construction lack any internal vapour barrier and higher humidity within the building resulting from human activities, resulted in an outward migration of water vapour. Over time, this not only saturated the internal insulation reducing its effectiveness, but it also resulted in delamination of the panel skins as the vapour froze when making contact with the outside skin. The dry Antarctic atmosphere also contributed to cracking and splitting of timber, not only impacting on the structural strength of the load bearing panels, but also exacerbating the ingress of melt water with the plywood faced panels. Most critically, the post-tensioning rods made it impossible to replace a damaged panel, so that the buildings lost their structural soundness over time. As a result, the effort required to keep the buildings warm increased considerably, and the additional heating increased the risk of fire. The very dry air would strip the moisture out of building materials, making them highly combustible, despite the cold (Smith, 1972). The availability of water for fire-fighting was limited as water had to be stored inside to remain liquid.

ESTABLISHMENT OF CASEY STATION – Elevated Buildings

This post-tensioned box building design reached its peak of development with the design of the original Casey station (1969-89). The roof panels were thickened to improve insulation and included a slight slope to help shed melt water (Brown, *et al*, 1968). The majority of Casey's buildings were elevated on a lattice of steel scaffolding in a determined effort to reduce the build-up of drifting snow. Wind tunnel testing was undertaken to determine the necessary elevation required to ensure that the elevated structure remained free from snow drifts. Testing of the curved leading edge was also undertaken to ensure structural stability under design wind loads.

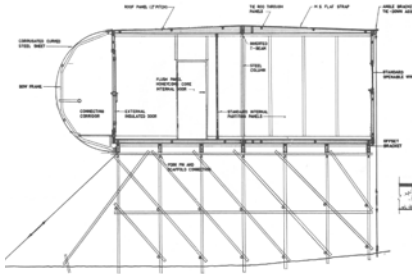		
Figure 4 A cross-section of the proposed aerofoil shape to eliminate snow build-up (Part Drg VA68/506/C)	**Figure 5** Load testing of the curved corrugated steel sheets for structural soundness (Photo: ANARE 13971)	**Figure 6** The distinctive shape of the "tunnel" and the lack of snow build-up at the doorways (Photo: PG Law)

Although the elevated 'wing' design (locally called the "tunnel") was successful in keeping the building clear of drifting snow, this elevated approach produced a number of additional specific problems. The elevation produced cold floors, and made the building prone to noise and vibration in high winds. There was also additional cost and construction time associated with initially grouting in scaffold starters into the ground and then of the elevated lattice of scaffold tubing itself.
The Casey buildings served to emphasise the problems integral to post-tensioned box design as the buildings installed onto the elevated lattice of scaffolding were still essentially the post-tensioned box design of Mawson and Davis. The system also limited the size and flexibility of buildings which could be produced, and because the panels were hand-made, the buildings were expensive (Incoll[2], 1991). The need for guy wires to secure them created obstructions around buildings and made snow clearing and vehicle access difficult. Designers were not then conscious of the effect of water vapour migrating through panel insulation. The exposed Casey panels rusted through from the inside very quickly (Gosbel & Holmes, 1982). Additionally, the rubber gaskets seals between panels hardened over time and consequently lost their effectiveness. As the seals could not be replaced, melt water penetrated the buildings reducing the efficacy of the insulation and exacerbating the rust to the skin of the panels. Although the elevated approach also included the separation of the building areas to provide enhance fire partitioning, fire risk was still high.

Figure 7 - The elevated, aerofoil shape of the "tunnel" proved very successful in eliminating snow build-up
(Photo: GE McInnes)

THE REBUILDING PROGRAM – Development of AANBUS

The original building design had served their purpose of establishing Australia's foothold on the Antarctic continent. This 'foothold' raison d'être had fashioned the original building design; such that building construction could be completed within a few days, using a methodology suitable for labour with little or no building expertise. That limited expertise approach was no longer possible with building of the "tunnel" at Casey as its complex elevated structure required the need for specific tradesmen working to a programmed works schedule (Incoll[1], 1991).

By the 1970s, the purpose of the stations had also changed from establishing and maintaining a 'foothold' to one which had become more focused on scientific endeavours. In a submission to the Australian Government, the Antarctic Division sought funds to rebuild its three continental stations in a manner that would be much more conducive for not only scientific endeavours, but also for comfortable and practical day to day living. The Division recommended that the standard of accommodation and facilities be much closer to those provided for scientists and personnel in Australia. Not only would 'Rooms with a view' be seen as possible, but necessary, to offset life in the harsh conditions (Incoll[1], 1991).

The Antarctic Division produced a design philosophy for rebuilding the station. Buildings were to be more economical and efficient; and higher standards of basic services and fire safety were to be adopted. Exterior panels needed to be replaceable and guy wires were to be eliminated. Additionally, there was also a need to change the notion of what a reasonable Antarctic lifestyle should be (Incoll[1], 1990). The buildings would need to be engineered to withstand design wind speeds of 80m/s and temperatures ranging from 5°C in summer to minus 40°C in winter, whilst maintaining a comfortable 19°C inside.

The first major innovation adopted was that much larger buildings would need to be constructed so that the floor area per unit of external surface could be maximised. This approach would not only reduce the cost of the most expensive element – the insulating cladding, but also the on-going heating demand. It would however, require considerable internal steel framing to accommodate the high design wind speed. The Antarctic Division began trials and experimentation in search of a framing and cladding system. After trialling buildings with fibreglass, wooden and asbestos cement clad insulating panels; laminated standard cool room panels were adopted. The installation of the structural steel frame eliminated the need for external guy wire making snow clearing a simpler task, which in turn reduced the potential for water ingress during the summer melt. The building design also enabled replacement of the panels should they be damaged after erection. However, these more complex structures required a different construction approach, with trial erections of the steel frame and cladding in Australia. This highlighted any fabrication and design errors prior to shipment and as a result hastened erection time on station (Antarctic Structural Group, 1984).

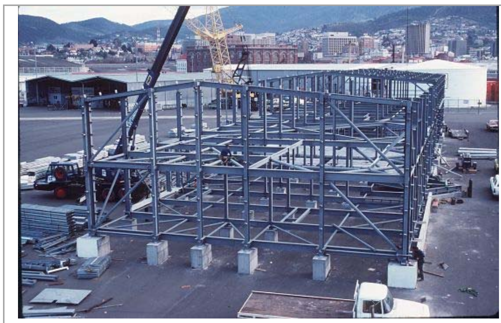

Figure 8 (above) and Figure 9 (middle): Trial erection of the Casey domestic building – Hobart Wharf 1983

(Photo: RD Reeves)

Figure 10 (above): Trial erection of the Mawson living Quarters in Melbourne in 1988

(Photo: J Hosel)

Separate, buildings with individual purposes also resulted in enhance fire separation and for the installation specific fire suppression systems based on the building's usage. The exterior panels consisted of face sheets of galvanised, pre-finished steel and a polystyrene foam core. The foam was chemically treated with fire retardant. However, designers accepted that heat on the panel faces would still melt the core. An internal double lining of plaster board with a nominal one hour fire rating was used to protect panels against internal fires in many buildings. The consequence was an overall wall thickness in the order of 800mm, which increased the overall size of the building. Significant testing of the panels were undertaken to determine the spacing of the wall girts and roof purlins to support the panels. Back-to-back purlins and girts at 1100mm centres were necessary to prevent flexure of the panels that would result in delamination of the steel skin from the insulating foam. The wall girts were designed to take the wind load on the panels only - the dead load of the panel being supported by a strip beam at the base. Testing also looked at pull out of the panel fixing bolts and lateral buckling of the double purlins and girts for the (then) 80m/s design wind.

Figure 11 - The original Living Hut (foreground) is dwarfed by the new Living Quarters at Mawson (Photo: A. Grant)

The steel frames were supported on concrete pedestals that were anchored to the bedrock. The anchors served two purposes: primarily to accommodate for up-lift due to wind action, and also to prevent vertical lift of the building as the water in the ground turned to permafrost at the end of summer. When water in the ground freezes, it expands and the only give is upwards. Unanchored foundations can be 'jacked' out of the ground over a number of freeze/thaw cycles.

The main drawback of this approach was the expertise and equipment required to undertake both the installation of the buildings, and their on-going maintenance. The construction personnel dominated berths on resupply voyages and beds on station, with very few beds available for scientists – not exactly appeasing the science community. This disadvantage aside, the buildings have been very successful and structurally superior to all previous building types in Antarctica (Antarctic Structural Group, 1984). It was called the Australian ANtarctic BUilding System (AANBUS) and it has since become the benchmark for building design in Antarctica (Incoll[1], 1991).

DAVIS LIVING QUARTERS– A fibre-composite building

The limitation of berths and beds on station for science during the rebuilding program was the catalyst for the next innovation in Australian Antarctic buildings. A new approach was developed to minimise the number of personnel required to erect a large building. The time-consuming construction method of AANBUS was a result of the secondary steel and its associated panel fixings, along with the covers and flashings across panel joints. A new fibre-composite building approach was developed where once again the exterior insulating panels would become part of the structural capacity of the building. Finite element modelling of the proposed building led to the structural design of both the exterior insulating panels and that of the structural steel supporting frame. The much larger panels and the minimalistic steel supporting frame greatly reduced installation time and effort, minimising the need for construction beds on station.

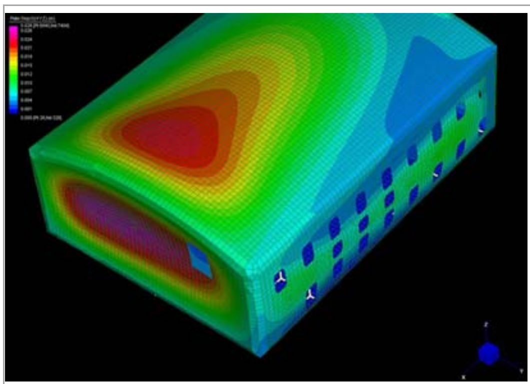

Figure 12
Finite element testing was undertaken to better understand key stress locations
(Source: AAD)

Figure 13
The structural frame has very little secondary steel, which greatly reduced installation time on station
(Photo: M Pekin)

An additional advantage of the approach was that panel fixings would be undertaken from the inside, rather than the AANBUS approach of fixings through the entire panel. This eliminated the 'cold-path' of the steel fixing from the external side of the building into the warm building interior. The fabrication approach also resulted in a completely sealed fibre-composite panel, producing a complete vapour seal. The fibre-composite approach did create its own set of challenges: the panels were installed with butt type joints, which would expand as the building was heated up from ambient temperatures (-5°C to +5°C) to the standard internal operating temperature of 20°C. The steel frame would undergo thermal expansion at a different rate to that of the fibre-composite panels, hence panel fixings able to accommodate for up to 20mm in differential expansion. An enhanced fire detection and suppression system was installed to reduce the fire hazard, which included a pressurized water cylinder to supply an initial 20 minutes of automated water to the sprinkler system, providing time for the deployment of the Station's fire system. A chemical suppression for the kitchen and hose reels fed from the station's water supply completed the system.

Figure 14
The new fibre-composite panels only needs supports at 3m centres and were fixed from the inside only (Photo: M Pekin)

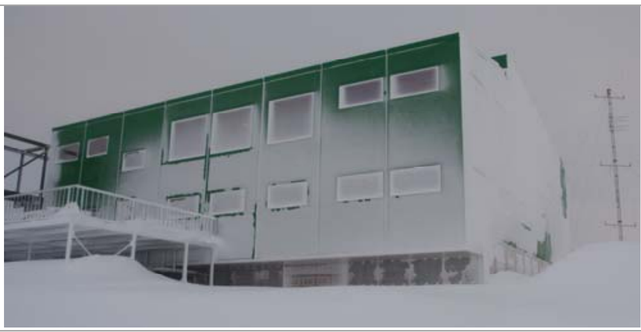

Figure 15
The new Davis LQ in snow, the fibre composite panels significantly reduced erection time and specialised construction personnel requirements. (Photo: M Pekin)

CONCLUSIONS

Australia's Antarctic program has increased dramatically since a party of expeditioners landed at Heard Island in December 1947 to establish the first ANARE station. They repaired a twenty year old shipwrecked sailor's hut for temporary accommodation while they erected four more huts, each built out of surplus WWII plywood pre-fabricated materials.

These original huts were a far cry from the facilities available today on the continental stations of Mawson, Davis and Casey. The pioneering work of the engineers and construction teams involved in Australia's Antarctic rebuilding program during the 1980s and 1990s was highly successful. The Australian ANtarctic BUilding System (AANBUS) became an internationally accepted benchmark in Antarctic and cold-region design. Many of these AANBUS buildings have exceeded their design life, and yet remain sound and in overall very good condition. Whilst the original function of a number of the buildings has been concluded, the overall building design has allowed for internal refurbishment for new purposes. The more recent buildings installed at Australia's Antarctic stations have continued the excellence required in structural engineering to provide habitable and functional buildings in the most extreme of natural environments.

ACKNOWLEDGEMENT

It is impossible to produce such a paper covering 50 years of Antarctic building design and engineering, without relying on the memories of the personnel involved and the written history available at the Antarctic Division over that period. Many thanks to many people, particularly those expeditioners who have donated their photos to the Antarctic Division providing so much valuable information.

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