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The performance of a surface station on an Antarctic ice shelf

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Abstract

Halley is a scientific station on the Brunt Ice Shelf, Antarctica. The three main buildings are wooden single-storey structures supported about 5 metres above the snow surface by steel platforms and columns. The buildings are raised annually to overcome the mean snow accumulation of 1 metre per year.

This paper shows the development of snow drifts around the buildings over the 5 years since construction began. Differential movement and inclination of the steel columns are described. Possible causes of this deformation, including creep within the snowdrifts, are examined.

1 Introduction

Halley is the fifth station of that name to be built on the Brunt Ice Shelf, on the coast of the Weddell Sea in the Antarctic. At Halley the ice shelf is about 150 m thick[1] and flows westwards at about 750 m per year[2]. The annual snow accumulation is about 1.2 m. The first four stations, constructed between 1956 and 1983, were built on or just under the snow surface and were allowed to bury. Although various designs were tried, within 7 to 10 years each building was badly crushed by the ice and had to be abandoned.

In 1987, the British Antarctic Survey (BAS) decided that Halley 5 should consist primarily of buildings maintained above the snow surface. The station was designed by Christiani and Nielsen (C&N) of Hamburg, using information concerning the Halley environment supplied by BAS. It was constructed and commissioned between the austral summers of 1988/89 and 1991/92.

2 Design

The three main buildings are wooden single-storey structures supported on raised and jackable steel platforms. The Accommodation Building (ACB), containing the living quarters and main services, is 65 m long, 15 m wide and 3 m high. It is supported by 20 steel columns. The two smaller buildings contain most of the facilities and equipment for the scientific work at Halley. The Ice and Climate Building (15 x 12 m) is supported by four columns and the Space Sciences Building (15 x 14 m) by six columns.

The ACB platform consists of ten parallel cross beams, each supported by two columns, 15.4 m apart. Between adjacent crossbeams, there are eight longitudinal beams that support the wooden building. The design of the science platforms is similar.

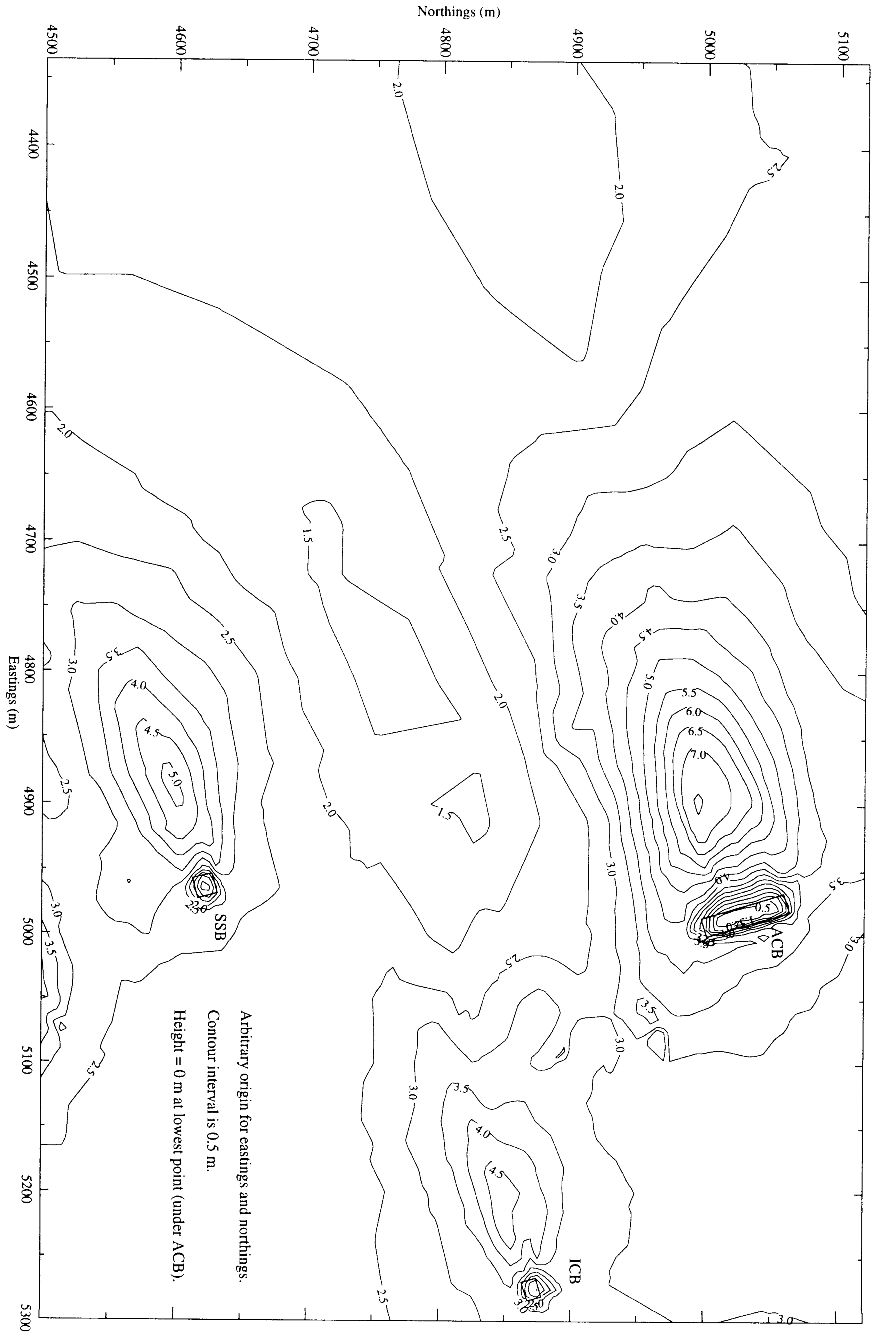
The original columns were 9 m long and were erected on wooden pad foundations 2 m below the snow surface. Extensions are added as the columns become progressively buried. The platforms are raised each summer by up to two metres and small adjustments made during the winter to keep the platforms level. Manual jacks are used and normally require two operators at each column. This method was chosen in preference to a more complex and expensive hydraulic system.

Some parts of the station were built below the snow surface, including interconnecting tunnels and facilities for snow melting and bulk fuel storage.

Although the design of Halley 5 was novel, experience was gained from C&N's design and maintenance of Filchner Station, a German summer base in the Antarctic, and from a visit to a Dew Line Radar Site on the Greenland Icecap. At the Cold Regions Research and Engineering Laboratory (CRREL), New Hampshire, wind tunnel tests were undertaken of a 1:200 scale model of the ACB (unpublished). These tests and knowledge of other work (for example, Mitsuhashi and others[3]) indicated that the buildings should be maintained at least 3.5 m above the snow surface to produce a stable snowdrift pattern.

The CRREL tests also determined that the ACB should be oriented with its long axis perpendicular to the prevailing wind. At Halley, the prevailing wind direction is about 075° and the secondary direction is about 180° to this. Almost all winds faster than 10 m/s come from these directions[4,5]. The rotation of the Brunt Ice Shelf was reported by Simmons and Rouse[6] to be less than 0.6° per year, and so was discounted.

Consequently, the platforms were built perpendicular to the line 075-255°. For simplicity, the axes of the buildings are called north-south and east-west.



Arbitrary origin for eastings and northings.
Contour interval is 0.5 m.
Height = 0 m at lowest point (under ACB).

Figure 1: Contour map of Halley, December 1993

3 Snow accumulation

The snow accumulation around Halley has been monitored regularly since construction began in January 1989. This work has included a full survey of the site every summer.

Figure 1 shows the relative positions of the three buildings and a contour map of the snow surface in December 1993. As expected, there is a snowdrift to the leeward (west) side of each building. It extends for about 300 m and the highest point is about 100 m from the building. There is a smaller snowdrift to the east and a trough underneath. The trough occurs because the wind that is deflected by the building and passes underneath is compressed and accelerated. This allows the wind to carry more snow particles, and so there is an area of low accumulation and scouring.

The sizes of the snowdrifts are affected by the heights of the platforms, which have varied from 3.5 m to 5.5 m, but the ACB snowdrift has always been the largest. In December 1993, it was over 5 metres higher than the undisturbed snow surface, and 2.5 m higher than the snowdrifts of the science buildings.

The science buildings are sufficiently small that much of the wind is deflected around the sides rather than underneath. The wind velocity is relatively undisturbed and less snow is deposited in the lee of the building. The ACB is four times wider and near the centre of the building the ends have minimal effect. Here, the flow can probably be well represented by a two dimensional model, such as that being developed by Moore[5].

The highest snow accumulation occurs in the lee of the southern end of the ACB. This is caused by the 'open platform', an unenclosed work area 7 m wide (see figure 2). It does not produce significant wind acceleration under the platform but does generate turbulence and snow deposition.

The snowdrift pattern at the north and south ends of the buildings are also affected by stairs and service shafts leading to the tunnels.

Figure 3 shows annual east-west profiles of the ACB taken near the southern end of the building. The most rapid growth occurred in the first two years. During 1992 and 1993 the peak to trough height was about 7 metres, but the snowdrift had not reached a stable state. The low accumulation around the columns in the first four years restricted the height that the platform could be raised, and so the platform became lower relative to the snowdrift and the general surface level. This encouraged more accumulation, especially in the area between the building and the peak of the western snowdrift.

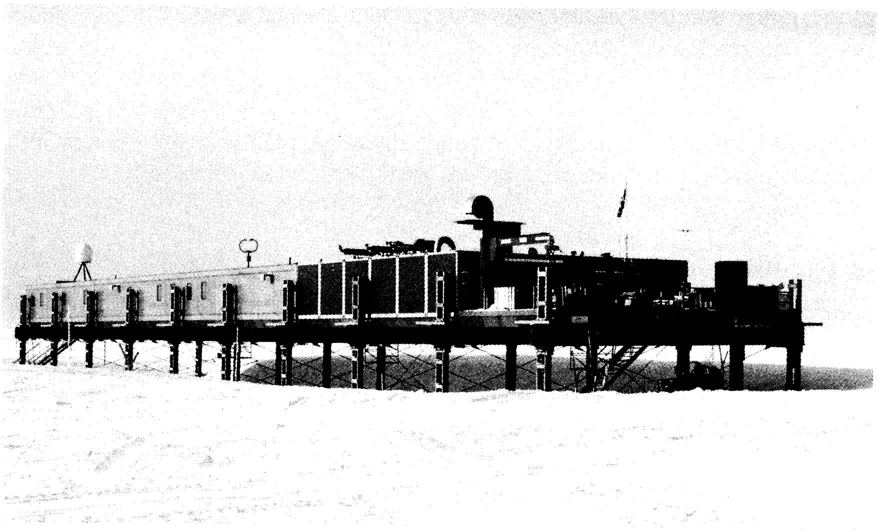


Figure 2: Photograph of ACB viewed from south-west, January 1992

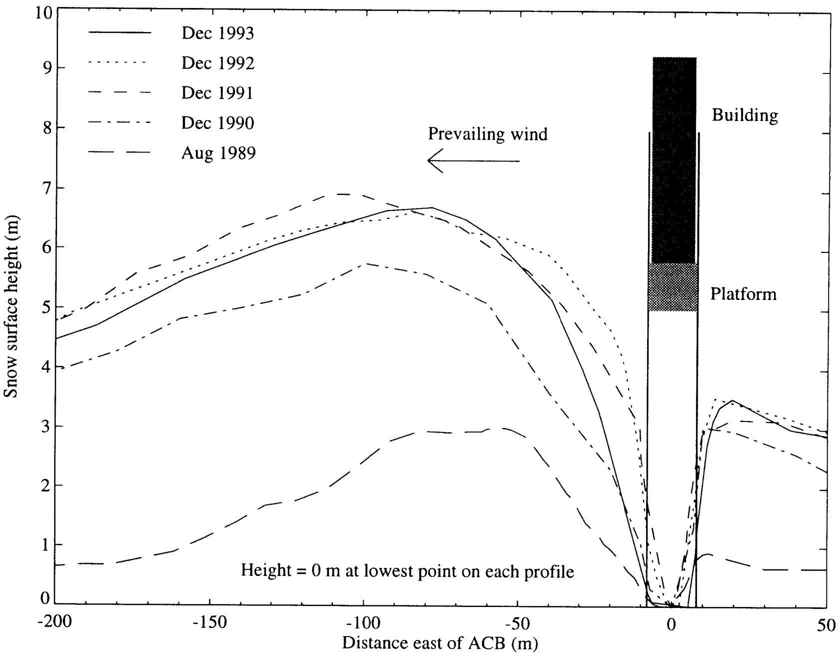


Figure 3: Annual snow surface profiles of the ACB snowdrift

By the summer 1992/93 the snowdrift had reached a state where remedial work was required. The problems it caused included restricting vehicle access to the building. It was also becoming apparent that the snowdrift was responsible for some of the deformation of the platform described below. Using a snowblower and bulldozers, the trough under the platform was filled in by 2 metres using snow from the western snowdrift. More snow grooming was required in 1993/94.

4 Column movement

The design of the platforms anticipated differential movement of the columns and contingency plans were made for the realignment or replacement of columns. Regular surveys have been conducted to ensure the safety of the buildings and to study the forces acting on them.

The survey of the columns included measurement of their relative positions, heights and inclinations. Figure 4 shows the relative heights of the ACB columns in December 1993, five years after construction. In each frame, the west column had risen 0.20 ± 0.02 m relative to the east column, equivalent to a slope of 13 per mille or 0.7°. Also, there was a generally upward slope from the columns at the southern end to those at the northern end of the platform.

The vertical movement of the columns has not been a serious problem. Its main consequence was that the platform had to be levelled almost every month. In the future it may be necessary to add extensions of differing lengths to make the top of the columns level again.

By 1991 it was evident that the ACB columns were leaning over towards the east side. In December 1993, the inclinations of the sections of the columns above the surface were measured using a spirit level. The east columns were leaning 31 ± 3 per mille to the east (away from the building) and 11 ± 3 per mille to the south. The largest inclination was 38 per mille or 2.2°. The west columns were leaning 6 ± 2 per mille east and 10 ± 5 per mille south. If it is assumed the columns were straight, then the foundations in each frame would have moved closer together by 0.20 ± 0.04 m.

Although the platform was still structurally safe, the inclination of some columns was too extreme for the jacks to be used to raise the platform. During the 1993/94 season most of the ACB columns were realigned to reduce their inclination. The load was taken off the column by supporting the crossbeam with a jack on a scaffold tower. Snow and ice was cleared from the column to within 3 to 5 metres of the foundation, and the column was pulled using winches and steel cables.

Due to the inward movement of the foundations, the east columns could

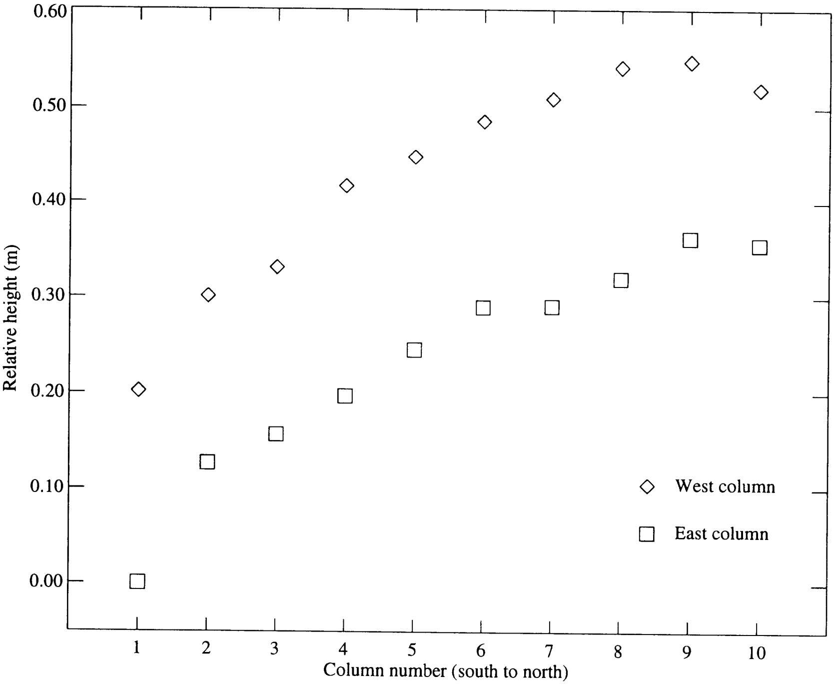


Figure 4: Relative heights of ACB columns, December 1993

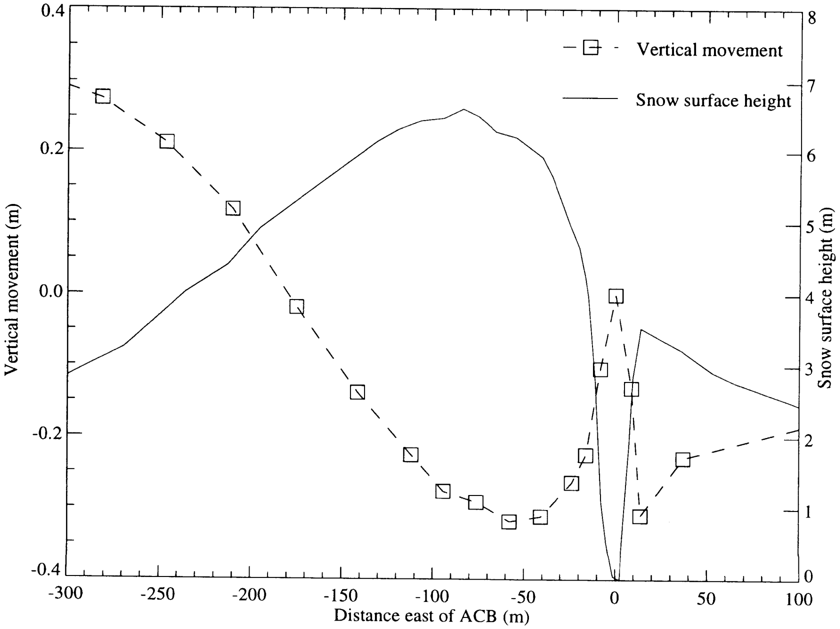


Figure 5: Vertical movement and surface profile of ACB snowdrift, 1992

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only be pulled westward until they touched the building and it was not possible to make them vertical. If the movement continues, it will become necessary to remove many of the columns and place new ones further out from the building. Two columns were replaced during 1993/94 to show that it was feasible. The old column was cut off two metres below the surface and the new foundation was placed one metre above the stump.

The columns of the science buildings moved less than those of the ACB, and not all moved in the same manner. No realignment has been necessary.

5 Discussion

The processes that may be involved in the deformation of the platforms include:

(a) The natural strain in the ice shelf
The principal horizontal strain rate in the vicinity of Halley is approximately 0.001 per year[7] and acts to move the foundations further apart. The calculated movement of the foundations is equivalent to a compression of 0.026 ± 0.005 per year. Limbert[8] measured the vertical strain rate near Halley as 0.0003 per year; this is not sufficient to account for a major part of the vertical movement of the columns.

(b) Uneven snow accumulation over the foundations
The snow surface around the east columns slopes downwards from east to west, producing greater loading on the east side of the foundations. This would tend to tilt the east columns to the east, but the movement has not been calculated. As the foundations become more buried the effect of the surface slope will diminish.

(c) Uneven loading on the platform
On the ACB, the heaviest loads are towards the south and west sides of the platform. This may account for most of the upward slope from the south to the north end, but it would decrease the rise of the west side compared with the east.

(d) The tension in the guy wires
To reduce vibration of the platforms in high winds, steel cables were fitted from each column to the opposite end of its crossbeam. The tension in the cables may have produced some of the east-west movement of the columns, but it is not believed to be the main cause. However, as a precaution, in 1993/94 the ACB cables were relocated so that they pulled from the columns outwards to anchors in the ice.

(e) Snow creep in the snowdrifts

Snow creep, caused by the snowdrifts deforming under their own weight, is believed to be the major cause of the movement of the columns. A survey programme was started in 1991/92 to measure the horizontal and vertical strain rates in the snowdrifts and around the Halley site. This work is not yet complete, but figure 5 is included here to illustrate the size of the movements observed.

The figure shows the vertical movement of aluminium poles, initially buried to 1.3 m depth, in an east-west line passing under the ACB near the southern end. The relative heights of the poles were measured to 1 mm accuracy with an optical level in January 1992 and January 1993.

6 Conclusions

Halley 5 has been operational since 1990 and provides a good environment for living and working in the Antarctic. Differential movement and inclination of the columns were greater than anticipated and studies have been undertaken to understand the forces involved. The remedial work carried out in 1993/94 was successful and showed that the station can be maintained for many more years.

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