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WIND TUNNEL MODEL STUDY OF ANTARCTIC SNOWDRIFTING

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ABSTRACT

A closed circuit boundary layer wind tunnel with a working section 900 mm wide and 600 mm high was built in the School of Civil and Mining Engineering, the University of Sydney for the study of Antarctic snowdrifting. Turbulent shear flow, which represents terrain category type 2 (AS 1170 - Part 2, 1989), was simulated. Sodium bicarbonate was chosen as model snow out of a number of different materials tested. Contour image of snowdrift at the leeward side of a model was generated by Moire fringe camera. The image was captured by microcomputer-based digital image-processing unit and then reprocessed by a contour-analysing software. The contour analysis allows the accurate comparison of snowdrift pattern of the model and prototype buildings. The result of snowdrifting simulation using model snow around an elevated Antarctic building was compared with field data (Mitsuhashi, 1982).

INTRODUCTION

Antarctica with its flat topography and katabatic phenomena has one of the highest wind speeds on earth, and the most extensive snowdrifting. The effect of this on Antarctic buildings is exacerbated by the year-long sub-zero temperature causing minimal melting of the snowpack. This often leads to on-going accumulation of snowdrift which causes problems ranging from inconvenience at entrances to their abandonment when innundated completely. Given this realisation, Antarctic building designers are thus confronted with minimal research data on snowdrifting, especially around buildings and structures.

Since the shape of snowdrift has complex form, there has been a limitation of analysing the shape of snowdrift. This limitation has been overcome with the combination of Moire fringe camera, inexpensive image processing boards designed for use with personal computers, and contour analysing software. This report starts with the evaluation of simulated turbulent shear flows in the wind tunnel and test results of a number of different potential model snow particles were reviewed. Model snowdrift shape around an elevated building was compared with the field data collected by Mitsuhashi (1982).

WIND TUNNEL

The wind tunnel is made of particle board, plywood, and steel angle frame and is capable of producing wind speeds up to 10 m/s in the 900 mm wide and 600 mm high testing section. The side wall and roof of the testing section are made of transparent acrylic boards and the roof section is removable. The fan is driven by a three phase motor rated at 15 KW and a variable speed controller was fitted to control the wind speed. The wind tunnel is shown in Plate 1. A plan view of the wind tunnel are described in Figure 1.

Air and model snow particles are sucked from slots, which are located at the beginning and the end of the working section, by a 0.45 KW centrifugal fan and then continually re-circulated into the beginning of the working section through a 80 mm diameter P.V.C pipe on the roof. The two slots located at the leeward side of the turbulence generating fence clear undesirable model snow particle deposition. Another two slots located at the end of the working section relieve pressure in the working section to prevent leaking of model snow particles.

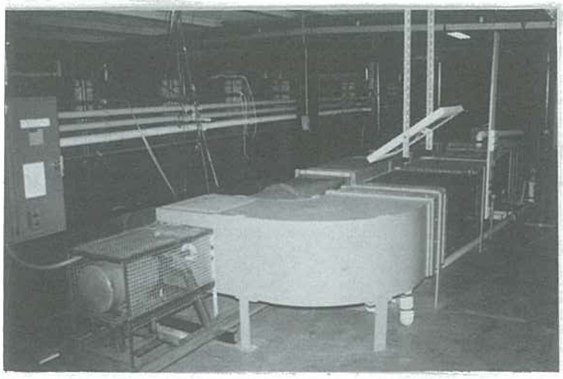

Plate 1. The closed-circuit low speed boundary layer wind tunnel for snowdrifting study

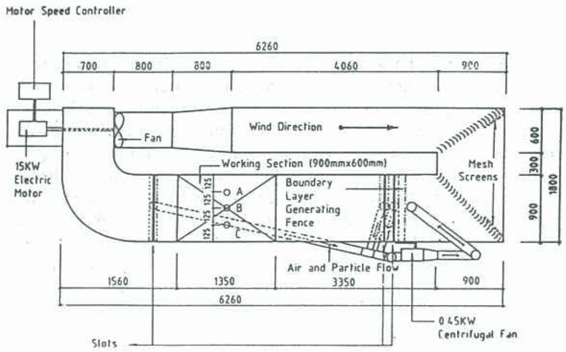

Figure 1. A plan view of the wind tunnel

MODELLING OF ATMOSPHERIC BOUNDARY LAYER

Similarity between model and prototype values of the following minimum parameters should be maintained to simulate an atmospheric boundary layer flow:

1) mean wind velocity profile;
2) turbulent intensity profiles;
3) Reynolds stress profile; and
4) turbulent length scale and spectrum.

The sites of Australian Antarctic stations Mawson, Casey and Davis are coastal sites comprising of relatively open flat ice-free rock during summer which becomes snow-covered for approximately 8 months during winter. This topography has been adopted as the prototype condition in this investigation. Therefore the first step was to simulate wind model approximated the terrain category type 2 as described by the Australian wind loading code (AS 1170 - Part 2, 1989).

In order to achieve a satisfactory boundary layer flow in the relatively short working section of the closed- circuit wind tunnel, an augmented growth method, with a combination of screens, roughness elements, and turbulence generating fence, was adopted. A 100 mm high fence were installed at the start of the working section to generate the large scale vortices. The floor of the working section was covered with low-pile carpets for a distance of 4 m downstream from the fence as shown in Plate 2.

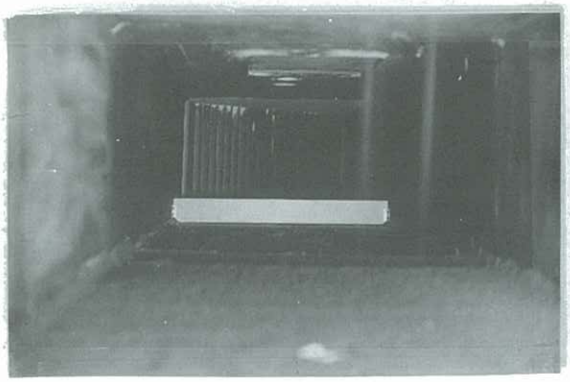

Plate 2. Simulation of turbulent boundary layer flow in the 600 mm x 900 mm low speed wind tunnel

The flow characteristics of the simulated atmospheric boundary layer, exclusive of model snow, were measured at three lateral positions 3.3 m downstream from the fence , at the centre of the working section and 125 mm on either side of the centre (A, B, and C as shown in Figure 1). A cross hot wire was used to measure profiles of mean wind speed, turbulence intensities, Reynolds stress and longitudinal velocity spectrum. Profiles from 25 mm up to 300 mm above the tunnel floor were measured at each of three lateral positions. The hot wire signals from the DISA Constant Temperature Anemometer were linealized, low-pass filtered to remove instrumentation noise, digitized by an 8-bit analogue to digital converter, and sampled by a micro-computer. Sample times were approximately 30 seconds.

Mean wind velocity profile at the three lateral positions are presented in Figure 2. A logarithmic law with a roughness height (Z_0) of 0.02 m in full scale (terrain category 2, AS 1170-Part 2, 1989) was found to have a reasonable fit with the experimental data. Longitudinal, lateral and vertical turbulence intensity profiles of a point B are plotted in Figure 3. Longitudinal turbulence intensity profiles are compared with profiles suggested by AS 1170 - Part 2, 1983 and 1989. The lateral turbulence intensity was about 94% of the longitudinal value, and the vertical turbulence intensity was about 80%. In an atmospheric boundary layer, pressure varies slowly with distance and therefore the longitudinal pressure gradient is approximately zero. The measured Reynolds stress profiles is reasonably constant with height as shown in Figure 4. The longitudinal turbulence spectrum was measured on the wind tunnel centre line at the height of 200 mm (equivalent to 10m in full scale) and plotted in Figure 5 and compared with the Harris - Von Karman spectrum. Figure 5 shows that there is a mismatch in the longitudinal velocity spectrum by a factor of approximately 3.5 for a nominal scale of 1/50.

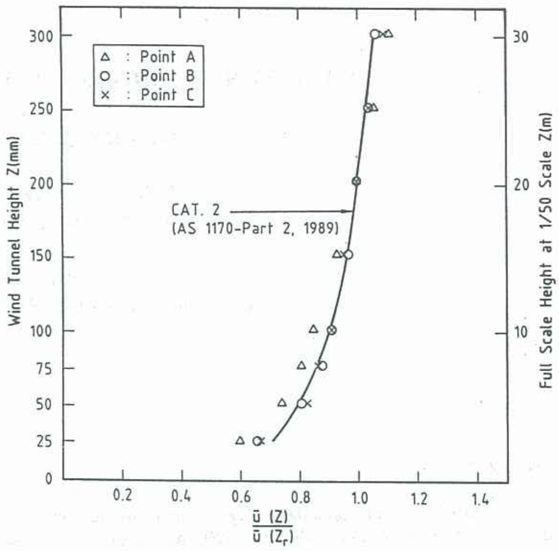

Figure 2. Mean wind velocity profile

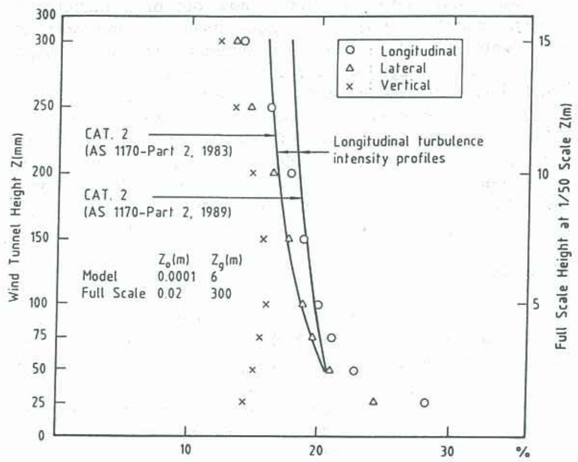

Figure 3. Turbulence intensity profiles

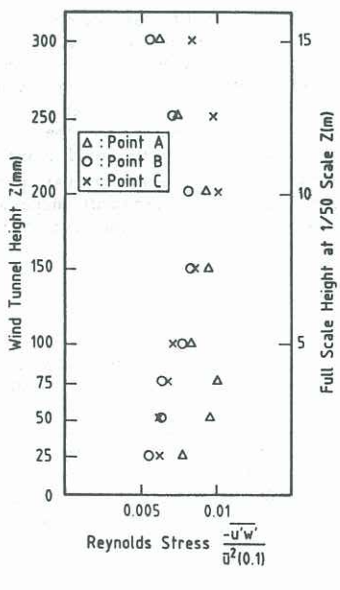

Figure 4. Profiles of Reynolds stress

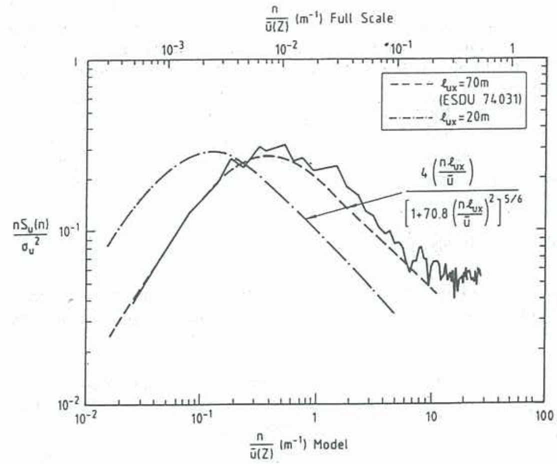

Figure 5. Longitudinal turbulence spectrum at 1/50 scale

MODEL SNOW PARTICLE SELECTION

Most researchers pointed out that the angle of repose of model snow and prototype snow (at greater than 90 degrees) should be approximately equal for simulation of drift patterns. Table 1 shows a summary of various model snow particles used and experimental techniques performed by other researchers. Although a simulation of snowdrift with a high angle of repose is considered a very important factor , none of those model snow particles has achieved this desirable property. Anno (1984) has achieved the highest angle of repose, 40 to 50 degrees, by using fine activated clay particles.

Name & Refer.	Year	Test Facility & size (m)	Flow Charac.	Structure tested	Geomet. scale	Model Snow	Part'le size(m)	Repose Angle
Finney	1939	open circuit wind tunnel	N/A	snow fence	N/A	sawdust & Mika Flake	N/A	N/A
Strom et al.	1962	open circuit wind tunnel 1x2x9.15	non-scale flow	Arctic building	1/10	Borax	0.1	N/A
Iversen	1980	open circuit wind tunnel 1.2x1.2x9.15	turb'lt b'ndary layer	highway	1/60 1/120	Glass Beads	0.05	34 deg.
Tabler	1980	frozen lake (full scale)	full scale	snow fence	1/30	natural snow	N/A	N/A
Anno & Konish	1981	open circuit wind tunnel 0.8x0.8x10	N/A	Forest & snow fence	1/300	activated clay particles	0.0015	N/A
Kind & Murray	1982	open circuit wind tunnel 0.4x0.4x11	N/A	snow fence	1/20 1/40	Expanded polyurethane & sand	0.6 0.2	30 deg. 35 deg.
Anno	1985	closed cir't. wind tunnel 0.4x0.4x5	turb't bn'dary layer	elevated Antarctic building	1/100	activated clay particles	0.0015	40 - 50 deg.
da Matha Sant'Anna & Tabler	1985	open circuit wind tunnel 0.9x0.9x10	turb't bn'dary layer	two level flat roof building	N/A	Fine sawdust	0.297-0.250	N/A

Table 1. A summary of various model snow particles used and experimental techniques performed by other researchers for snowdrift modelling

Ten different particles were tested in a search for a suitable model snow which produces the correct drift shape around the Observation Hut of Japanese Antarctic Showa Station as per Mitsuhashi (1982). Table 2 shows characteristics of model snow particles tested in the wind tunnel. Commercial sodium bicarbonate (standard grade), with a high angle of repose of approximately 90 degrees, was found to produce the most realistic snowdrifting shape. In addition, it was commercially available in large quantities, economical and is not explosive in the closed circuit wind tunnel. However it was found that corn flour and co-polymer were highly explosive (Field,1982) in the given experimental environment. The bulk density of sodium bicarbonate was 1295 kg/m^3 and the statistically measured mean effective diameter of the particles was approximately 50 μm. Plate 3 shows a photomicrograph of sodium bicarbonate.

The model snow particles were distributed to a uniform depth of 20 mm at the beginning of the working section

	Name	Particle Size (μm)	Density (Kg/m^3)	Comments
1	Acrylamide Copolymer	3	800	White granular Highly water swellable. Explosive in the wind tunnel condition.
2	Wheat Starch	3	690	Fine white powder Explosive in the given condition.
3	Calcium Carbonate	3	550	White powder. Cohesive
4	High Grade Calcium Carbonate	27	700	High whiteness and consistent fine particle size. Cohesive
5	Fine Kaolin	1	400	High purity natural hydrous aluminum silicate. Very cohesive
6	Crystalline Silicate	7.5	1200	White powder. Cohesive
7	Magnesium Silicate	16	1000	Cohesive. Predominantly finer than 75μm
8	Sodium Bentonite Clay	15	880	Cohesive. 12% moisture content
9	Calcium Oxide	2.7	660	Cohesive. 0.2 % moisture content
10	Sodium Bicarbonate	50	1000	$NaHCO_3$: 99% Na_2CO_3 : 1%

Table 2. Characteristics of various model snow particles tested in the wind tunnel

Plate 2. Photomicrograph of Sodium Bicarbonate

before the wind tunnel was started. Wind velocity at the centre of the working section was maintained at 6 m/s. The particles were picked up and suspended by the turbulent air flow and circulated in the wind tunnel. The simulated drift around a scale model of Observation Hut of the Showa station (1/50) was compared with the field data (Mitsuhashi,1982) and shows good agreement as shown in Figure 6. The reverse rimming formation at the leeward end of the roof was realistically simulated as shown in Plate 4. This structure is found in Antarctica (Rohde, 1987).

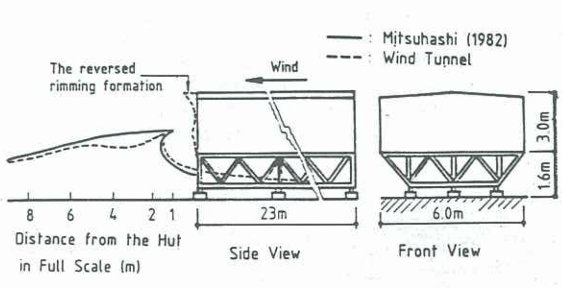

Figure 6. Snowdrift profiles: full scale measurements from Mitsuhashi (1982) compared to a wind tunnel simulation of the Observation Hut at Japanese Antarctic Showa station

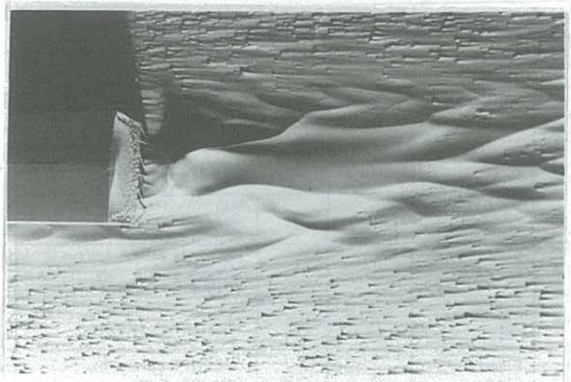

Plate 3. Simulated snowdrift at the leeward side of the model building

DATA ANALYSING SYSTEM

Contour images of snowdrift shapes were generated by grid-projection type Fujinon Moire Camera (Model FM 40). This camera has fixed focus (1.8 m) and photographing area is 900 mm x 600 mm. Layout of experimental set up is shown in Plate 5. Measuring sensitivity is 2.5 mm height

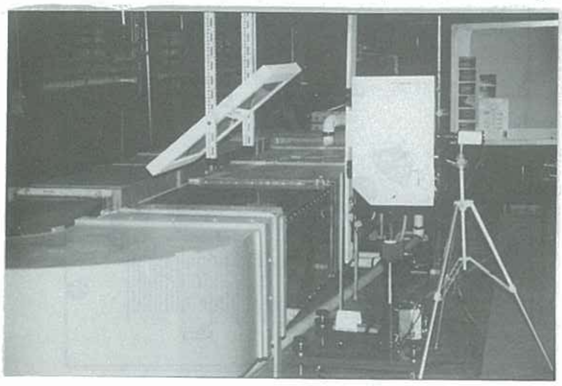

Plate 4. Layout of experimental set-up

(black to black stripe). Those contour images were captured by "Newvichip" CCD camera equipped with 2/3 inch zoom lens. Captured contour image (see Plate 6) was then sent to image-processing system. This system consists of a Matrox Pip-1024 image - processing board installed in a IBM-compatible personal computer. The pip-1024 is a plug-in board that enables an IBM-compatible personal computer to perform frame-grabbing operations on CCD camera signal. The board has one megabyte of eight-bit memory that is partitioned into quadrants. When a frame is grabbed, it is digitised into a 1024 x 1024 array of pixels with each pixel assigned a grey shade from 0 (dark) to 255 (bright). The host microcomputer was a NEC APC IV (IBM AT-compatible) with a Multisync EGA board and a 66 megabyte hard disk. Frame grabbing is in real time at the standard rate of 1/30 second. The grabbed image was then processed with contour analysing software which is an

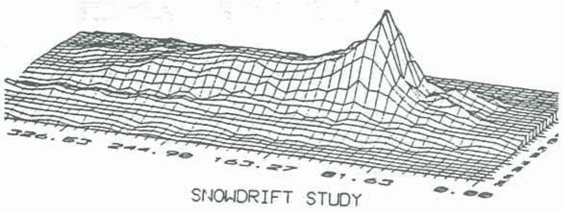

Figure 7. Perspective drawing of a simulated snowdrift shape

interactive, menu-driven graphics program that produces three-dimensional surface representations for output to the printer. The program also gives the volume of snowdrift. The resulting form is displayed as it would appear to an observer at some specified viewpoint. In a perspective drawing of the simulated snowdrift around the model as shown in Figure 7, parrallel lines on the surface appear to converge as they become more distant to provide the illusion of depth.

CONCLUSIONS

The main conclusions from this research of Antarctic snowdrift modelling around an elevated building are as follows;

1. A boundary layer flow (terrain category type 2, AS 1170-Part 2, 1988) was simulated at a scale of 1/50 in the relatively short working section of a closed circuit low-speed wind tunnel by an augmented growth method which consisted of a combination of screens, a turbulence generating fence and roughness elements. The simulated flow represents coastal areas of Australian Antarctic Territory.

2. Sodium bicarbonate was chosen from ten different model snow particles tested in the wind tunnel. It produced a high angle of repose which was almost 90 degrees. The simulated snowdrift shape around the scaled model (1/50) of the Observation Hut at Japanese Antarctic Showa Station and shows a good agreement with field data (Mitsuhashi, 1982).

3. Generated snowdrift at the leeward side of the model was taken by a Moire fringe camera with contour images and CCD camera. The image was sent to an image-processing system and reprocessed by the contour analysing software to produce three-dimensional surface representations for output to the screen and printer. The end result of processed snowdrift images were used for comparison of snowdrift shapes generated by a 1/50 scale model of Japanese Showa Antarctic station and field data.

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