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⦿Technical Paper

Simulation and Analysing Methods of Snowdrifting around an Elevated Building in Antarctica

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南極 建物주위에 形成되는 雪堆現象의 模擬實驗 및 分析方法에 關한 硏究

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Key Words: Antarctic Snowdrifting (南極 雪堆現象), Atmospheric Turbulent Boundary Layer Wind (大氣境界層亂流), Wind Tunnel(風洞), Model Snow(모조눈)

抄　錄

南極의 雪堆現象을 模擬實驗하기 위하여 閉鎖式 大氣境界層亂流風洞을 濠洲 시드니大學 土木工學科에 制作 設置하였다. 鐵鋼과 100*mm* 높이의 矩形판자 및 촘촘한 양탄자 등의 實驗要素를 使用하여 境界層剪斷亂流를 誘導發生시켰다. 誘導發生된 亂流는 濠洲領 南極領土의 海岸地域에 부는 亂流와 비슷한 類型을 띄었다. 자연눈에 代替할 物質을 찾기 위하여 몇몇 種類의 가루를 使用하였으나 중탄산 나트륨이 가장 適合한 것임이 判明되었다. 南極建物모델 주위에 實驗을 通해 쌓인 눈의 形態는 미쑤하시(1982)의 現地調査結果와 比較되었다. Moire fringe 카메라를 使用하여 쌓인 눈의 形態로 부터 等高線무늬를 型象化시켰으며 image processing unit을 利用하여 等高線무늬를 捕捉한 후 等高線 分析 software를 利用, 눈의 形態와 量을 分析하였다.

1. Introduction

Antarctica with its flat topography and katabatic phenomena has one of the highest wind speeds on the earth, and the most extensive snowdrifting. Snowdrifting around Antarctic building causes problems ranging from inconvenience at entrances to their abandonment when innundated completely. Between these extremes, problems vary in danger and cost. They include: covered windows and vents, blocked fire escapes, psychological effects (Holmes, 1982), high energy consumption and buildings being pushed off their footings. Given this realization, Antarctic building designers are thus confronted with minimal research data on snowdrifting, especially around buildings and structures.

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This study 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). Since the shape of snowdrift has complex form, there has been limited analysis of the snowdrift shape. 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.

2. Development of a Wind Tunnel

Preliminary snowdrift modelling study was conducted by trial experiments in an open-circuit wind tunnel. In that experiment, model snow particles were introduced into a $400mm \times 600mm$ working section and then discharged into an air-bag which measured $3m \times 4m \times 3m$. Unfortunately this method resulted in a severe dust problem, required considerable manning for its operation, and constituted a health hazard. Consequently, it was considered necessary to build a closed circuit wind tunnel. The new closed circuit boundary layer wind tunnel is made of particle board, plywood, and steel angle frame and is capable of producing wind speed up to $10m/s$ in the 900 mm wide and $600mm$ 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 $15kW$ and a variable speed controller was fitted to control the wind speed. The wind tunnel is shown in Plate 1. An elevation and a plan view of the wind tunnel are described in Figures 1 and 2 respectively.

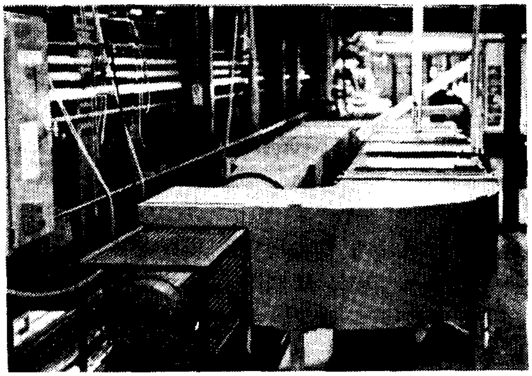

Plate 1 The closed circuit low-speed boundary layer wind tunnel for snowdrifting study

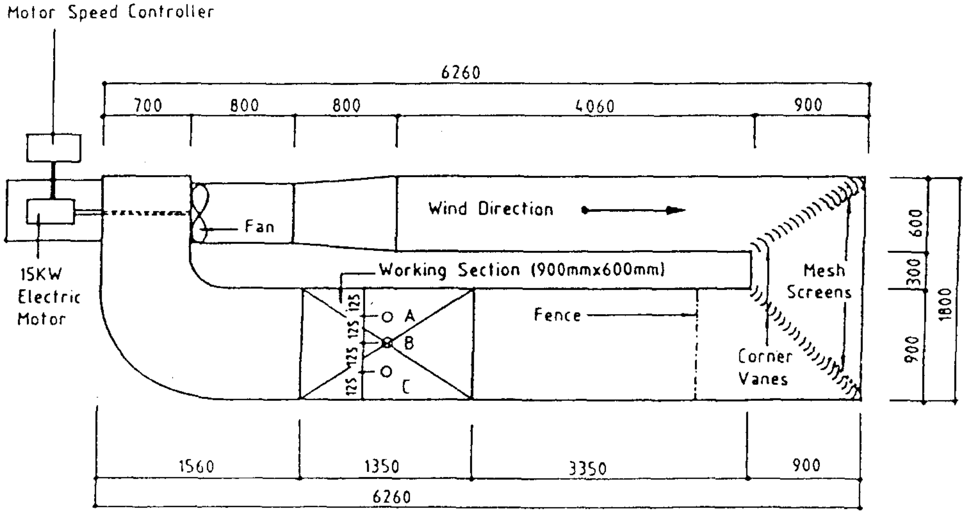

Fig. 1 A plan view of the wind tunnel

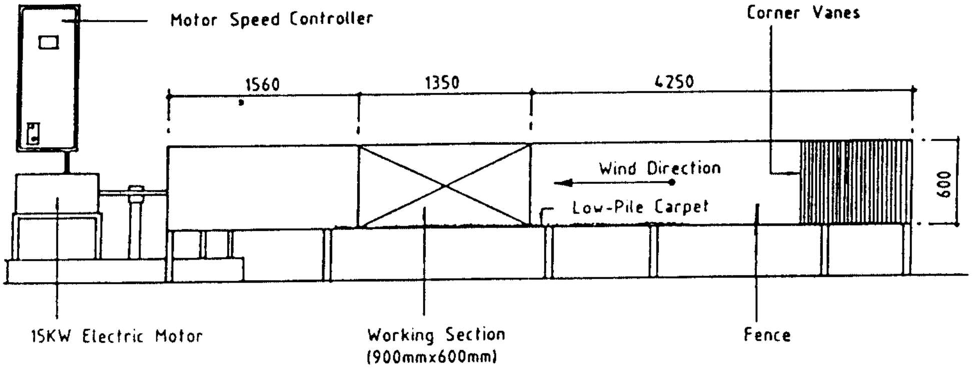

Fig. 2 A side view of the wind tunnel

3. Model Snow Particle Selection and Snowdrift Shape Analysing System

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)[2] has achieved the highest angle of repose, 40 to 50 degrees, by using fine activated

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

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 1×2×9.15	non-scale layer	Arctic building	1/10	Borax	0.1	N/A
Iversen	1980	open circuit wind tunnel 1.2×1.2×9.15	turb'lt b'ndary layer	highway	1/60 1/20	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 0.8×0.8×10	N/A	Forest & snow fence	1/300	activated clay particles	0.0015	N/A
Kind & Murray	1982	open circuit wind tunnel	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 0.4×0.4×5	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 0.9×0.9×10	turb't bn'dary layer	two level flat roof building	N/A	fine sawdust	0.297- 0.250	N/A

clay particles.

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[6]. Table 2 shows characteristics of model particles tested in the wind tunnel. Commerical 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. Corn flour and co-polymer both have favorable characteristic but were highly explosive in the given condition[8]. The bulk density of sodium bicarbonate was approximately $1300 kgf/m^3$ and the statistically measured mean effective diameter of the particles was approximately $50 \mu m$. Plate 2 shows a photomicrograph of sodium bicarbonate.

The model snow particles were distributed to an approximate uniform depth of $20 mm$ at the beginning of the working section before the wind tunnel was started. Wind velocity at the centre of the working section was maintained around $6 m/s$. 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 the Showa Station (1/50) was compared with the field data of Mitsuhashi[6] and shows good agreement as shown in Figure 3. The reverse rimming formation at the leeward end of the roof, which was commonly found in Antarctica[13], was realistically simulated as shown in Plate 3.

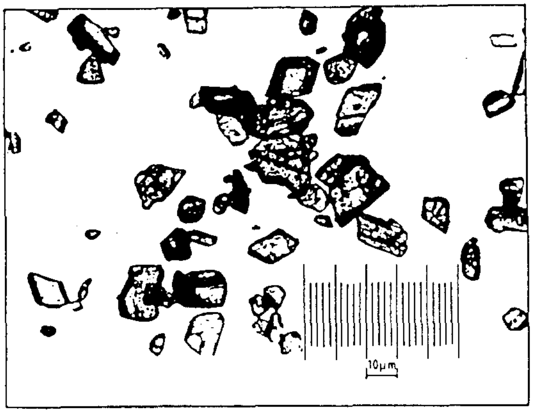

Plate 2 Photomicrograph of sodium bicarbonate

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

	Name	Particle size (μm)	Density (kgf/m^3)	Comments
1	Acrylamide Copolymer	3	800	White granular Highly water swellable. Explosive in the given 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 purity natural hydrous 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 $75 \mu m$
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%

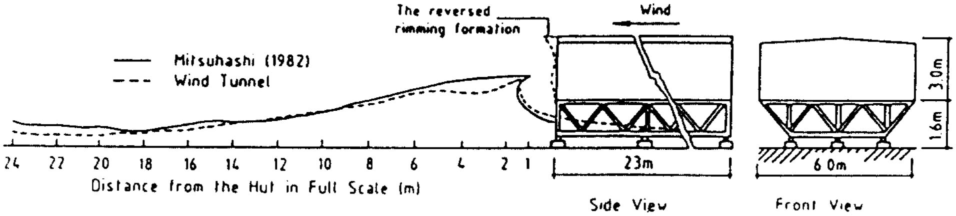

Fig. 3 Snowdfrft profiles : full scale measurements from Misuhashi (1982) compared to a wind tunnel simulation of the Observation Hut at Japanese Antarctic Showa Station

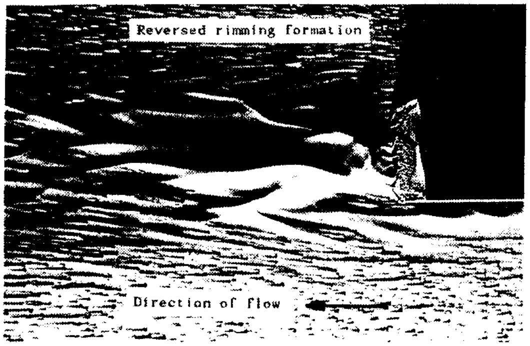

Plate 3 Simulated snowdrift at the leeward side of the model building and the overhang top edge formation

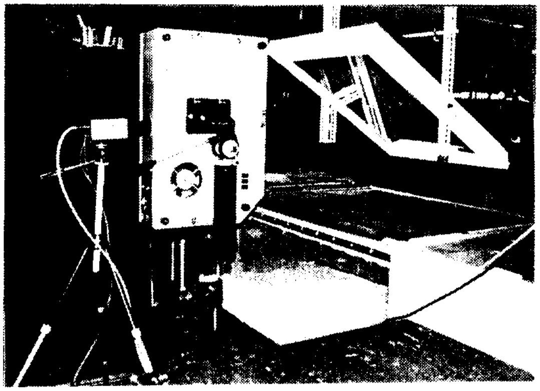

Plate 4 Layout of experimental set-up

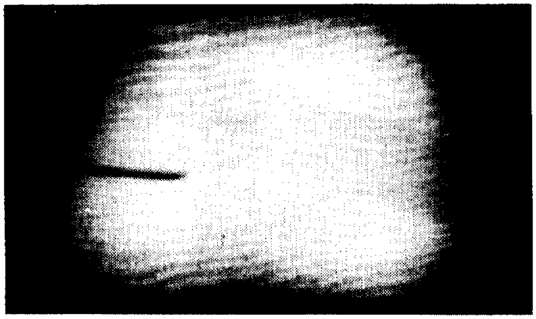

Plate 5 Contour image of snowdrift shape around the model of Japanese Showa Station in Antarctica

Contour images of snowdrift shapes were generated by a grid-projection type Fujinon Moire Camera (Model FM 40). This camera has fixed focus (1.8*m*) and the photographing area is 900 *mm*×600*mm*. Layout of experimental set up is shown in Plate 4. Measuring sensitivity is 2.5*mm* height (black to black stripe). Those contour images were captured by a "Newvichip" CCD camera equipped with 2/3 *inch* zoom lens. Captured contour image (see Plate 5) was then sent to an image grabbing and 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 the 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 1024×1024 array of pixels with each pixel assigned a grey shade from 0 (dark) to 255(bright). The system inputs images only in black and white, though a three-color version is available. There are also eight independently selectable look-up tables, each allowing for the display of 256 colors chosen from a palette of over 16 million.

Accompanying the hardware is a software library of simple commands designed to eliminate the need to interface directly with the image board. These commands enable a user to perform a wide range of image-processing tasks including frame input and output, look-up table manipulation, screen graphics, and image convolution. Also the library of software can be accessed by either Fortran or C programs. Linking the routines with a higher-level language can increase speed and flexibility. The interface was written in C program rather than Fortran to achieve customised, user-friendly, menu-driven software package. Using the menu, it is possible by using only a few key strokes to grab a frame, store a frame on disk, or to perform a number of other tasks. The host microcomputer was a NEC APC IV (IBM AT-compatible) with a EGA 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 the contour analysing software which is an interactive, menu-driven graphics program that produces three-dimensional surface representations for output to the screen, printer, or plotter. The program also given the volume of snowdrift. The resulting form is displayed as it would appear to an observer at some specified viewpoint. In a perspective drawing as shown in Figure 4, parallel lines on the surface appear to converge as they become more distant in order to provide the illusion of depth.

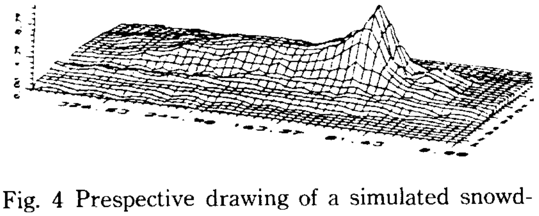

Fig. 4 Prespective drawing of a simulated snowdrift shape

4. Modelling of Atmospheric Turbulent 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 fit closely that of an open terrain, described in As 1170.2-1989 as terrain category 2, has been adopted as the prototype condition in this investigation.

Natural growth method is the preferred method for the simulation of an atmospheric boundary layer flow in a wind tunnel. However it requires a long wind tunnel test section 10 to 20 times the required boundary layer thickness. 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 100mm high fence were installed at the start of the working section to generate the larger-scaled vortices. The floor of the working section was covered with low-pile carpets for a distance of 4m downstream from the fence.

The flow characteristics of the simulated atmospheric boundary layer, exclusive of model snow, were measured at three lateral positions approximately 4m downstream from the fence, at the centre of the working section and 125mm 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 analogue to digital converter, and sampled by a micro-computer. Sample times were approximately 30 seconds.

The boundary layer flow with the model snow particles blowing over the snow-covered working section was measured with a pitot-static tube. Profiles from 25*mm* up to 200*mm* at the same three lateral positions were measured. The pressure signals from the pitot-static tube were measured using an electronic micromanometer, digitised by means of an analogue to digital converter, and sampled by a micro-computer. Sample times were approximately 30 seconds and five samples were averaged for each measurement.

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 without model snow and the terrain category type 1 with model snow as described by the Australian wind loading code (AS 1170-2, 1989).

Mean wind velocity profiles at the centre positions are presented in Figures 5 (in logarithmic law) and 6. A logarithmic law with a roughness height (Z0) of 0.02*m* and 0.002*m* in (terrain category 2 without snow and terrain category 1 with model snow respectively. The Antarctic snow field measurement data (Budd et al. 1965) for three different snowfield conditions and of three different roughness heights also show a good agreement with simulated mean wind velocity, as shown in Figure 7 (in log-linear format). It is

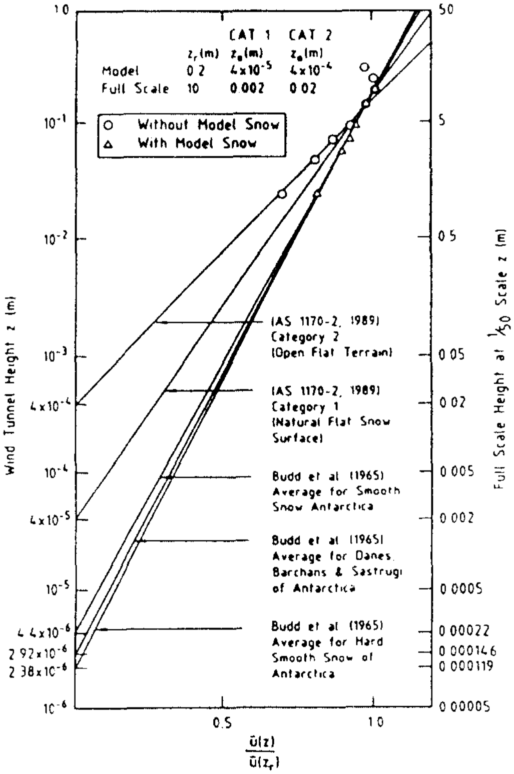

Fig. 5 Mean wind velocity profiles

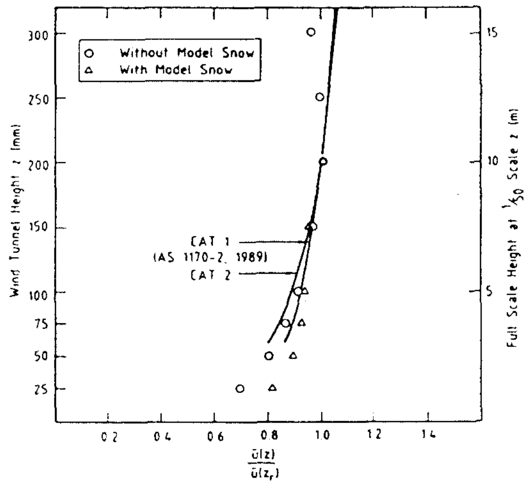

Fig. 6 Mean wind velocity profiles

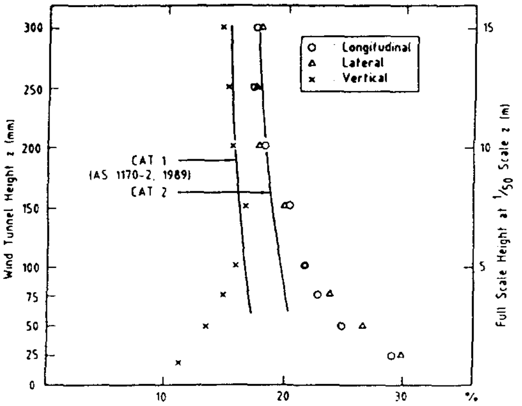

Fig. 7 Turbulent intensity profiles

interesting to note that the introduction of model snow particles caused a change in the flow characteristic from that of terrain category type 2 to a terrain category type 1. Longitudinal, lateral and vertical turbulence intensity profiles are plotted in Figure 6. Longitudinal turbulence intensity profiles are compared with profiles suggested by AS 1170-2, 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 7. The longitudinal turbulence spectrum is used to determine the distribution of turbulence energy as a function of frequency which gives a measured size of turbulence eddies. A velocity spectrum was measured at the wind tunnel centre line at a height of 200*mm* and plotted in Figure 8. The measured spectrum was compared with ESDU 74031 (1974) and shows that there is a mismatch by a factor of 3.5. Surry (1982) has indicated a mismatch by a factor of 2 or 3 is acceptable for the measurement of unsteady loads on low to a medium rise structures. However the effect of such a mismatch on snowdrift simulation is uncertain at this stage.

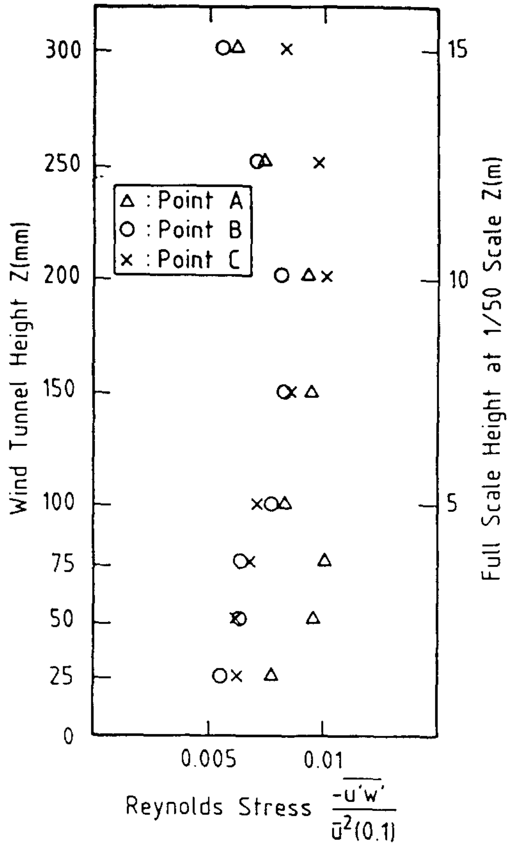

Fig. 8 Reynolds stress profiles

5. Conclusions

The main findings of the current investigation are as follows ;

1) A turbulent boundary layer flow (terrain category type 2, AS 1170−2, 1989) was simulated at a geometrical scale of 1/50 in the relatively short working section of a closed circuit low-speed wind tunnel. An augmented growth method which consisted of a combination of screens, a turbulence generating fence and roughness elements was used. The simulated flow is considered to be represent 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 the Japanese Antarctic Showa Station shows a good agreement with the field data⁶⁾.

3) The mean wind velocity profiles of the snow blowing condition over the snow-covered terrain category type 2 was simulated. The introduction of the model snow particles caused a change in the turbulent flow characteristics from terrain category type 2 to type 1 (AS 1170.2−1989). This change occurs in the coastal area of Australian Antarctic stations seasonally. The roughness height of the simulated terrain category type 1 was well matched with the field data (Budd et al. 19 65) of three different snowfields.

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

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MECHANICAL BEHAVIOR OF MATERIALS, TESTING AND EVALUATION OF MATERIALS, LIFE ASSESSMENT AND LIFE EXTENSION OF FATIGUE AND CREEP LOADED STRUCTURES, STIMULATION AND EXPERT SYSTEM, DATA ACQUISITION AND EVALUATION THROUGH COMPUTER TECHNOLOGY, COMPONENT DESIGN FOR INTEGRITY.

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