FULL-SCALE/MODEL-SCALE COMPARISONS OF WIND PRESSURES ON THE TTU BUILDING

ROFAIL, A.W.

Engineering Consultant, Windtech Wind Engineers Pty Ltd., Level 16, 9 Castlereagh St., Sydney, NSW 2000, Australia.

Abstract

The recently established Texas Tech University (TTU) Experimental Building, has been designed to facilitate the collection of comprehensive directional full-scale data. Significant full-scale data has already been accumulated. This present study presents a comparison between the model-scale measurements in Windtech's boundary layer wind tunnel and full-scale measurements, as well as model-scale measurements at Colorado State University (CSU). Wind tunnel data obtained by Windtech was found to be in good agreement with full-scale data. This paper attempts to explain the reason for the good agreement.

MODELING OF THE TTU EXPERIMENTAL BUILDING

This building is essentially a rectangular prism and has dimensions 30 x 45 x 13 ft. (9.1 x 13.7 x 4.0 m). A description of the TTU Experimental building was given by Levitan et al (1992). Model scales of 1:100 and 1:50 were tested in Windtech's boundary layer wind tunnel. Figure 1 shows photographs of the 1:100 scale model in the wind tunnel.

The wind structure modeled in the wind tunnel was based on the AS170.2-1989 definition of a wind structure for a category 2 (open country) terrain. The line of the mean velocity profile, as estimated by AS1170.2-1989 is approximately equivalent to a power- law exponent of 0.15. This is considered the equivalent of the local wind structure as described by Levitan et al (1992) which reported a mean power-law exponent of between 0.14 and 0.16. Figure 2 shows the mean wind speed and longitudinal turbulence profiles of the wind model. While turbulence levels seem to be lower than the code estimate for open country terrain at the heights of 20 m and above for the 1:50 scale wind model, it is actually very close to the field data obtained at the TTU site by Chok, C.V. (see Cermak et al, 1991).

The normalised power spectral density function for wind speed at 10 m height, at 1:50 scale, is presented in Figure 3. The ratio of the integral length scale, L_{ux}, in the wind tunnel varies from the field data reported by Levitan et al (1992) by a factor of 2.5. Field data obtained by Chok, C.V., reported in Cermak et al (1991) reported an average integral length scale of 140 m, with a range between 60 m and 260 m. The CSU wind model is reported to have an integral length scale of 60 m at a 10 m height (see Cermak et al, 1991).

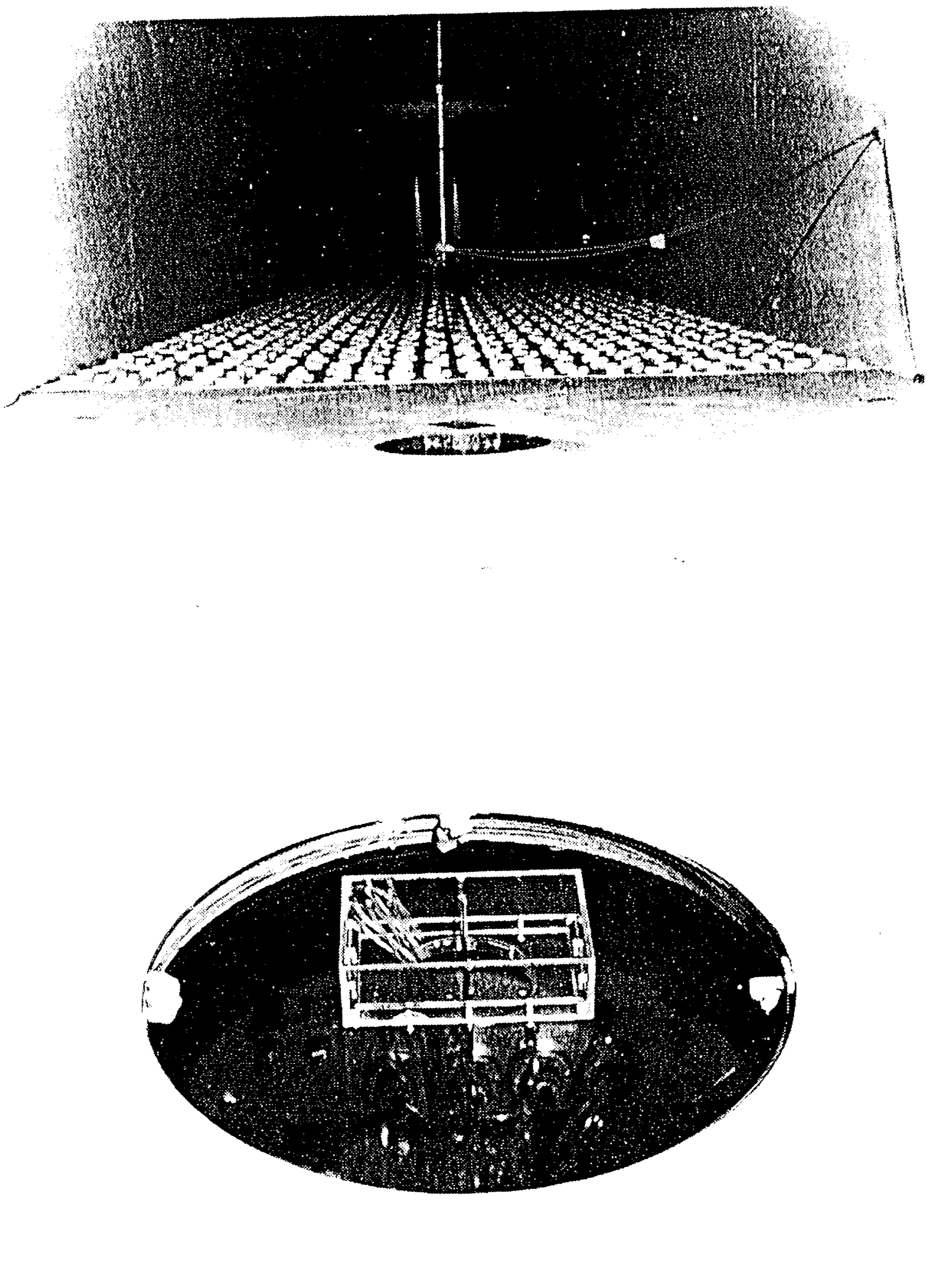
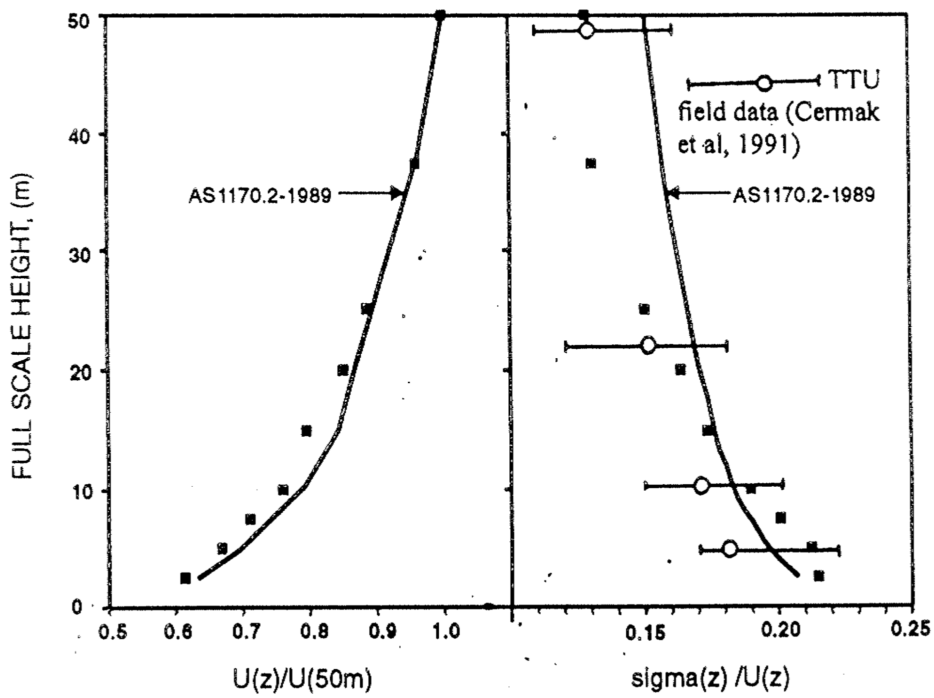
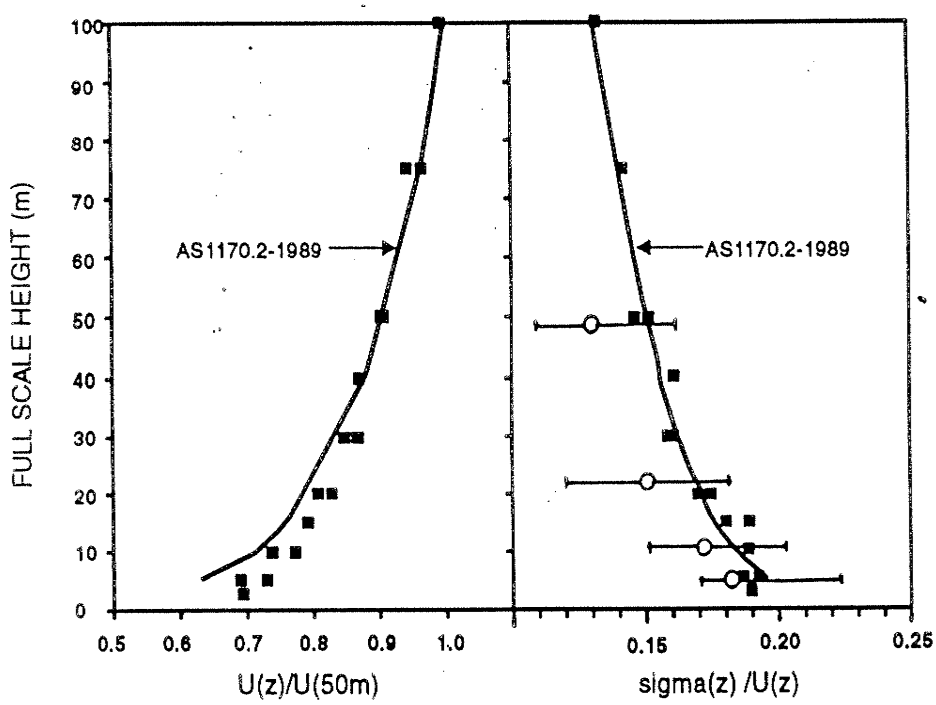


Figure 1. 1:100 scale TTU model in Windtech's boundary layer wind tunnel.

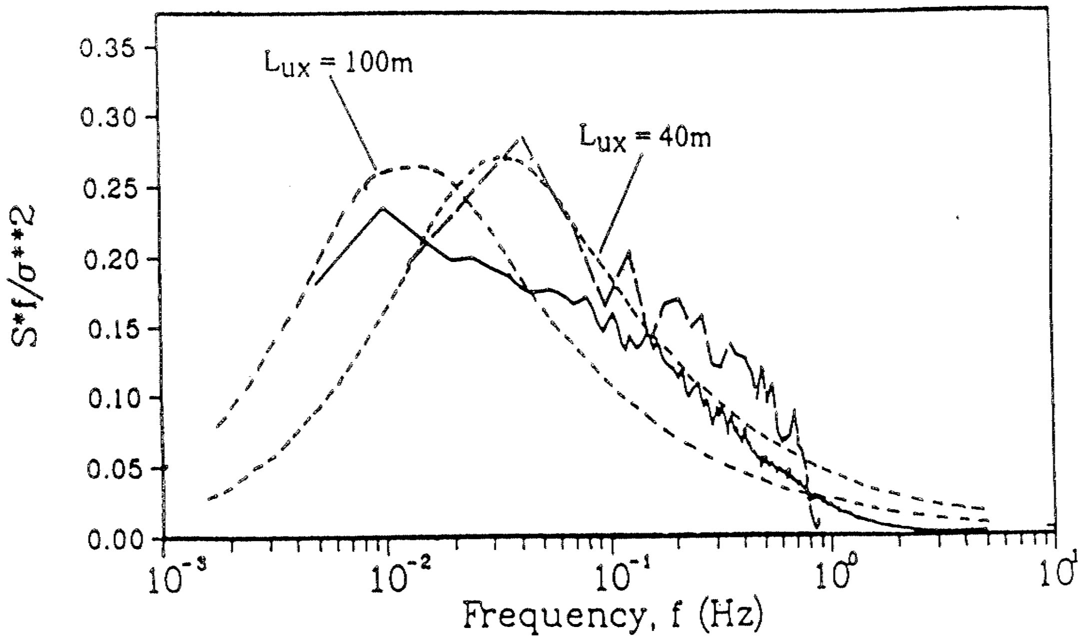


(a) For 1:50 scale open country terrain



(b) For 1:100 scale open country terrain

Figure 2: Mean Velocity and Longitudinal Turbulence Profiles in the wind tunnel compared with field data and code estimates.



LEGEND: ________ Full-scale data,
— — — — Wind tunnel data (1:50 scale),
- - - - - - - Empirical data, ESDU-74031 (1974).

Figure 3. Normalised Power Spectral DensityFunctionsfor wind speeds at 10 m height above ground

The wind tunnel has a cross section of 2.0 x 2.6 m and a fetch length of 16 m. The airflow in the wind tunnel is generated by a 75kW double inlet centrifugal fan. The appropriate boundary layer flows were produced through the use of combinations of spires, barriers and roughness blocks. For the 1:50 scale wind model, a set of six 1.25 m spires are placed 1 m upstream of a 0.4 m trip board and 50 x 50 x h mm roughness blocks (where h varied between 30 and 50 mm). For the 1:100 scale category 2 terrain, a set of six 1.25 m spires are placed 1 m upstream of a 0.5 m trip board and 10 x 20 x 40 mm roughness blocks.

A sample length of 30 seconds was used for the 1:50 scale model tests and 18 seconds for the 1:100 scale model tests. The velocity scale for the 1:50 scale model was 1.2:1 and was 1:1 for the 1:100 scale model tests. This makes the sample length equivalent to 30 minutes in full-scale time for both model scales.

DATA ACQUISITION AND ANALYSIS

Three pressure tap locations were selected for this comparative study. These are considered representative of the various types of pressure signals (i.e., windward, leeward and separated and reattached flows). The tap locations measured were 50101, 50209 and 42206. Tap number 50101 is located at the corner of the roof, 0.36 m from either wall. Tap number 50209 is located near the edge of the roof, 0.6 m away from the longer wall and 2.8 m from the shorter wall. Tap number 42206 is located at the centre of the longer wall of the building. Figure 4 illustrates the locations of the pressure taps and the convention for wind angles. Taps 50101 and 50209 provide examples of separated and reattached flows. Tap 42206 provides an example of windward, leeward, separated and reattached flows.

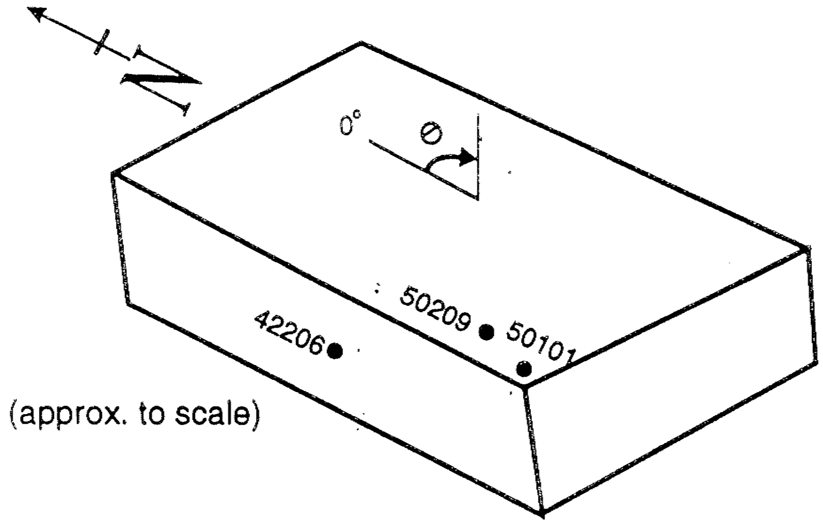


Figure 4: Locations of pressure taps on the TTU model

Vinyl tubing was connected from the tap locations to a Type J48 Scanivalve pressure scanning switch. The Vinyl tubes had a calibrated length of 1.00 m and an internal diameter of 1.37 mm. The pressure system was based on the leak tube system described by Gerstoft et al (1987). The system was calibrated by using the method reported by Holmes et al (1987). The pressure measurement system had a flat response (to within 11 percent) to 295 Hz. No resonant peaks were detected beyond that range. The pressure scanning switches were connected to Honeywell 163 pressure sensors. The frequency response of the pressure measurement system is illustrated in Figure 5.

The pressure signal was digitised using a Hewlett Packard 3561A Narrow Band Real Time Analyser. The signal was low pass filtered at 400 Hz and sampled at 1000 Hz. For the 1:100 scale model, these frequencies correspond to full-scale value of 4 Hz and 10 Hz, respectively. These match exactly with the actual full-scale situation, as reported by Cochran et al (1992).

Peak pressures were analysed using the standard Upcrossing technique. This involves the derivation of a statistical peak based on the number of crossings of the pressure signal at a number of pressure levels within the range of the signal. These pressure levels are spaced out in steps of a quarter of a standard deviation of the signal being analysed. The total number of levels vary typically between 12 and 20 for negative pressures and between 8 and 16 pressure levels for positive pressures. Rofail et al (1992) found that results using the standard Upcrossing technique become stable for signals of 30 minute duration or more. The effect of the difference in sampling time with respect to the 15 minute sample length in the full-scale measurements is expected to be negligible. Past research into the effect of sample length on peak pressures using the standard Upcrossing technique (Rofail et al, 1992) indicated a mean variation of approximately -3 percent for a 30 minute sample and -5 percent for a 1 hour sample, when compared with a 15 minute sample. Note that a negative variation indicates a lower magnitude.

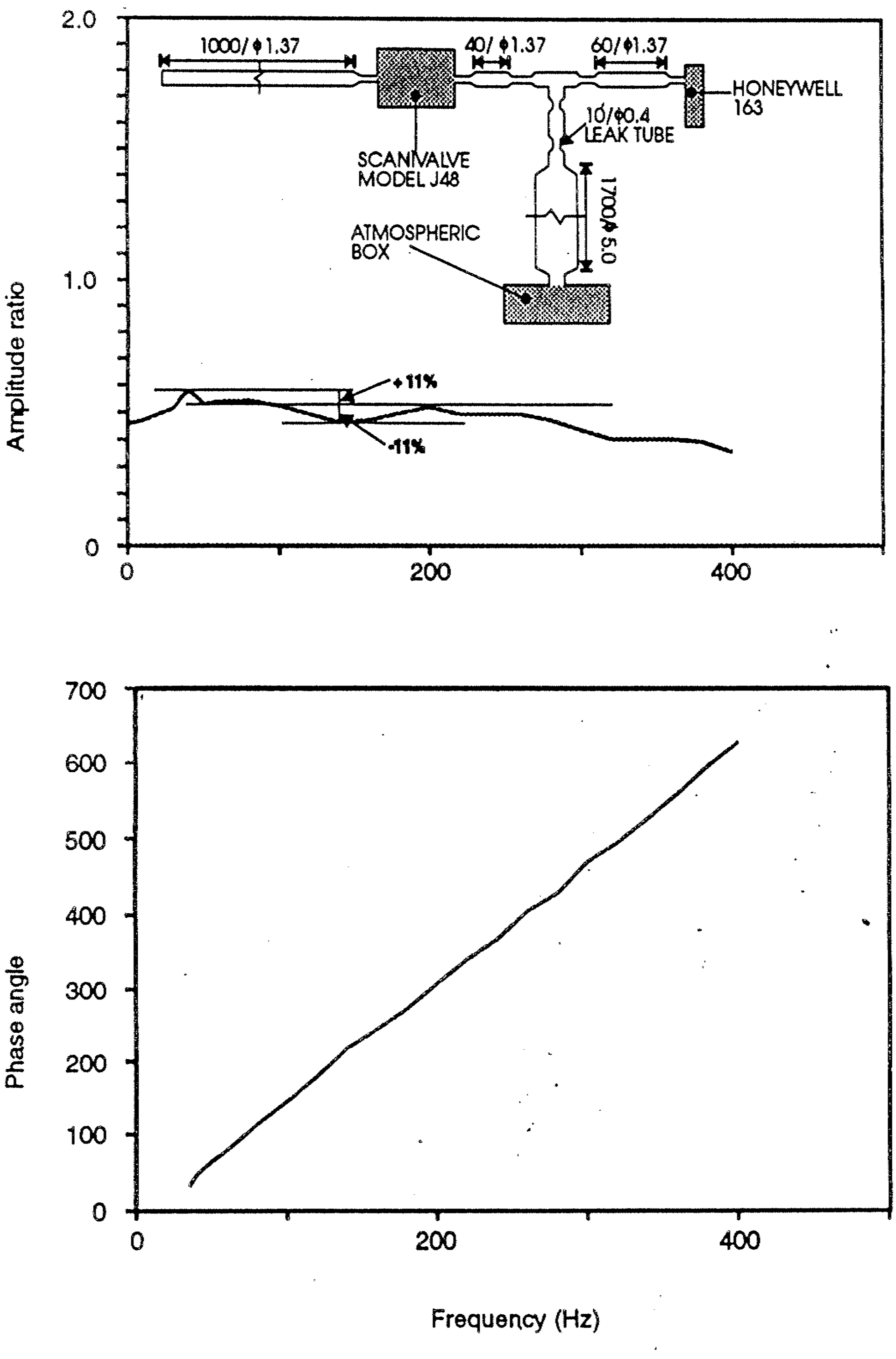


Figure 5: Frequency response of Windtechs pressure measurement system

The number of crossings at the various pressure levels are fitted to a Poisson function, which permits a linear distribution. Fisher Tippet Type I parameters are derived from the line of best fit and a statistical extreme value is obtained by the following relationship;

Extreme Value = U + 0.5772/a

Where U and 1/a are the mode and dispersion of the Upcrossing distribution, respectively and 0.5772 is the Euler constant.

A comparative study has been carried out by Rofail (1991) into the effect of various methods of analysis on the maximum and minimum peak pressures. It can be deduced from the above that the statistical extreme value, as derived from a 30 minute sample, using the standard Upcrossing method varies in magnitude by an average of -5 percent for negative pressures and +5 percent for positive pressures when compared with the average of 4 consecutive hourly extreme values, which are similar to the peaks used by Cochran et al (1992). Note that the percentage variation in the negative signals remained approximately constant for the various types of flow regimes.

Directional pressure measurements were obtained at 5 degree intervals. Reference pressure measurements were taken at roof height. Variation in the reference pressures was generally within 5 percent. This error was halved by averaging the reference pressures at the beginning and end of each run. Results are presented in the form of pressure coefficients. A pressure coefficient is defined as the ratio of the local point pressure to the mean velocity pressure at the reference height.

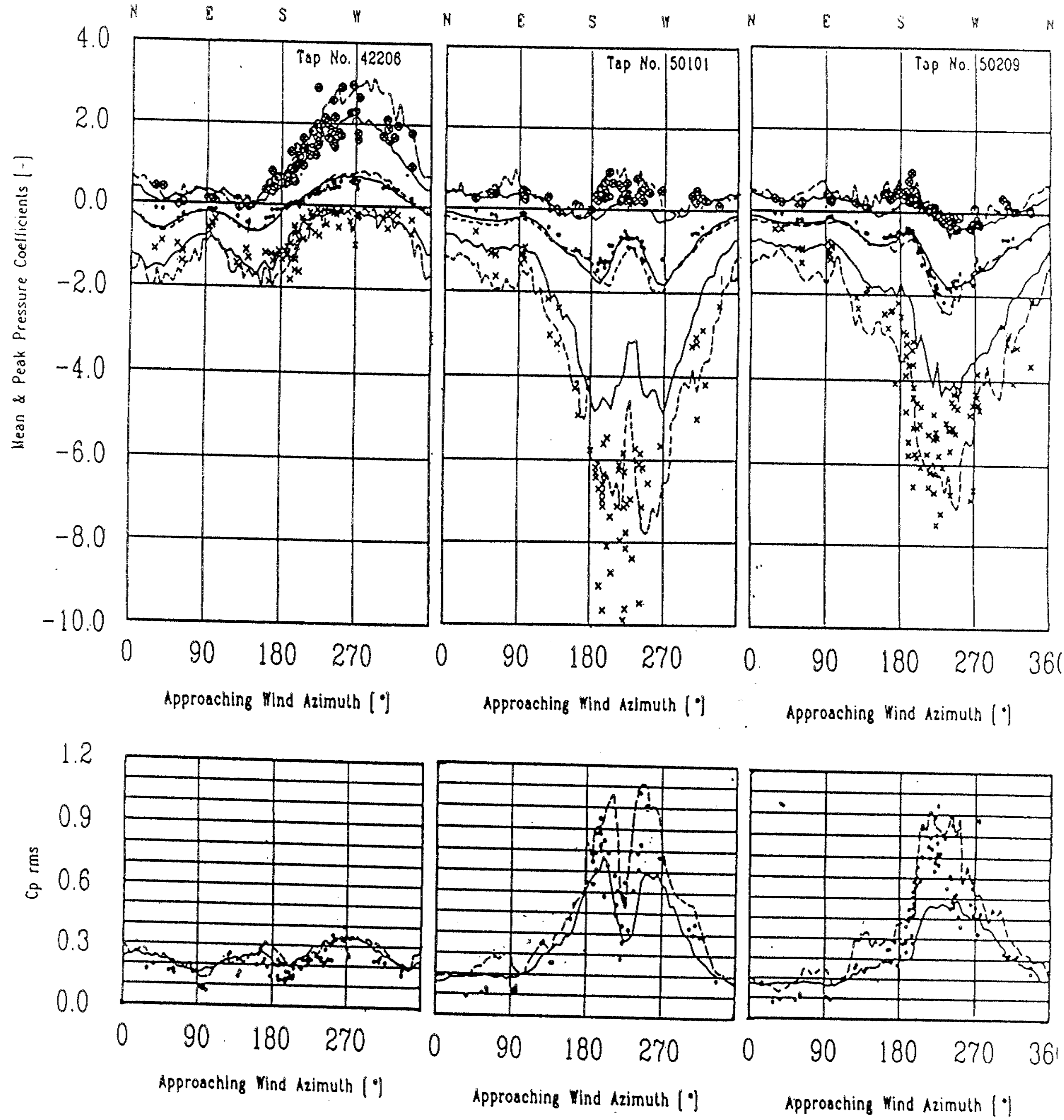
COMPARISON OF 1:100 MODEL DATA AND FULL-SCALE DATA

The results presented in this section are a comparison between the 1:100 scale model data by Windtech and those reported by Cochran and Cermak (1992) of Colorado State University (CSU) and the TTU full- scale measurements. These are presented in Figure 6.

Among other researchers who have presented comparative studies between TTU model and full-scale measurements are Okada et al (1992). However, the results are questionable, considering that their pressure measurement system has a flat frequency response upto only 100 Hz and the pressure signal was low pass filtered at 50 Hz (thus filtering a significant amount of energy in the higher frequencies). This explains why mean pressure coefficients obtained by Okada et al (1992) were comparable to the full-scale data while the rms and peak pressure coefficients were well below the range of full-scale data.

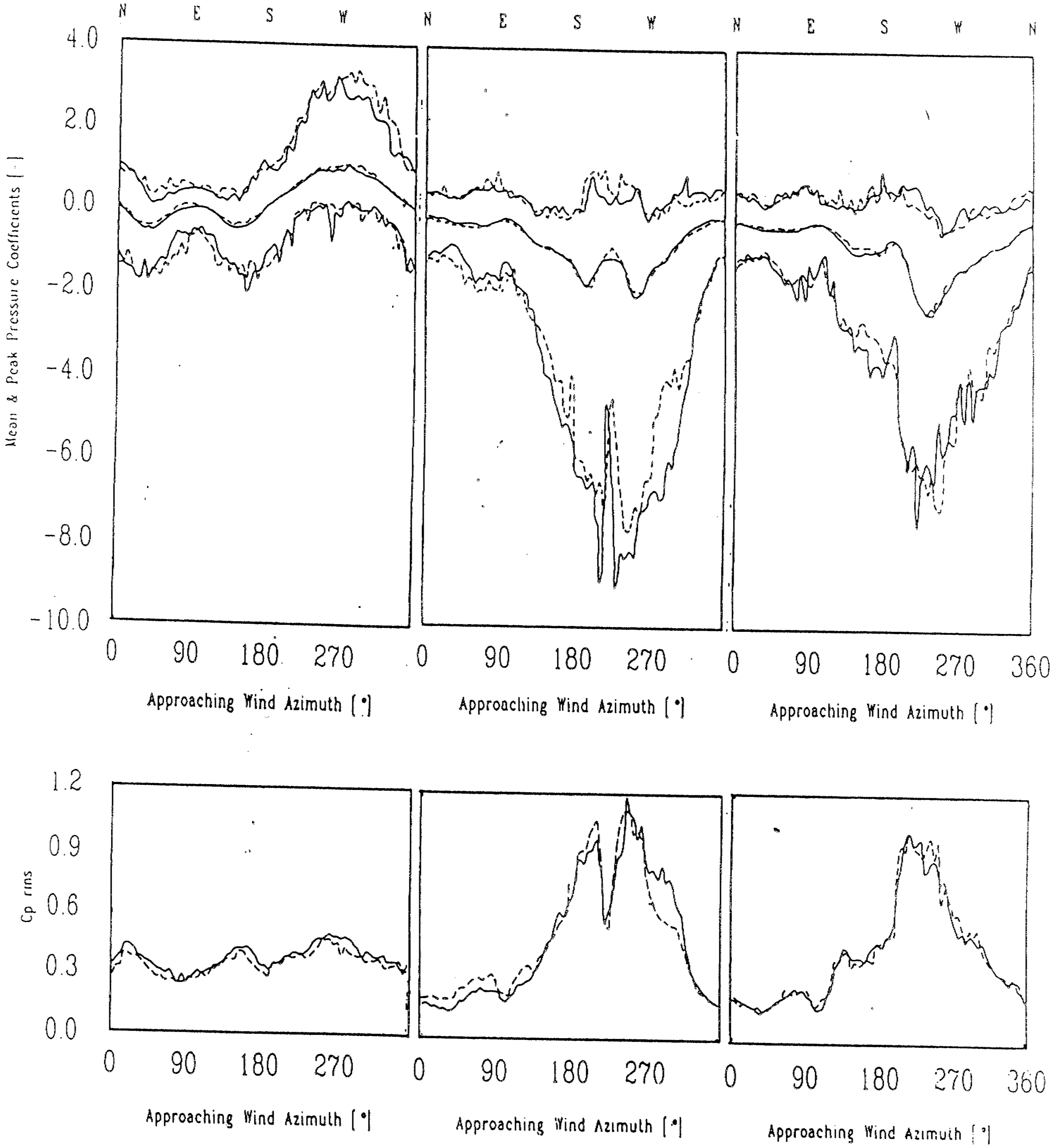
The mean pressure coefficient data are generally in good agreement with the full-scale data for both the Windtech and CSU results.

The peak rms pressure coefficients as predicted by Windtech were within 10 percent for the wall pressure data and within 4 percent for the roof pressures.



Legend: {symbols} Full-scale data
——— CSU 1:100 model scale data
- - - - - - Windtech 1:100 model scale data

Figure 6: Comparison of TTU full-scale data with 1:100 scale model data by Windtech and CSU.



Legend: ________ Windtech 1:50 model scale data
\- - - - - Windtech 1:100 model scale data

Figure7: Comparison between 1:100 scale and 1:50 scale model data by Windtech.

Windtech's rms pressure coefficients as well as the peak pressure measurements are in very good agreement with full-scale data. Generally, peak pressure coefficients are generally within 10 percent of full-scale data. The only exception to the above are the peak negative pressures from tap 50101 and between azimuths of 200 and 245 degrees, where Windtech's results under-estimate the full- scale data by approximately 25 percent. This is a significant improvement over the CSU results which under-estimate the full-scale data by approximately 50 percent for this tap position. The cause for the discrepancy between the wind tunnel results by Windtech and CSU is not clear.

The effect of method of analysis of the peak pressures has been discussed. While the upcrossing method may have some advantages in terms of repeatability of results, the statistical extremes derived from this method is clearly not the cause for the large variation between the Windtech and CSU results. For the 1:100 scale tests, both Windtech and CSU results are based on a velocity ratio of 1:1. This eliminates the possibility of a Reynolds Number effect. The sampling frequency of the CSU data was 1800 Hz and therefore is not the cause for the discrepancy. The modeling of the wind spectra has been has been discussed and generally indicate that the variation between wind tunnel and full-scale is generally acceptable, particularly since the TTU is a low-rise building. However, this does not explain the difference between the Windtech and TTU results, which are based on similar integral length scales in the wind tunnel.

The only test parameters which may possibly explain this difference is the frequency response of the pressure measurement system and the low-pass filtering frequency. As reported above, the frequency response of Windtech's pressure measurement system was within ± 11 percent upto 295 Hz, with no resonant peaks beyond this range. In addition, there was no significant attenuation upto 400 Hz. The signal was low-pass filtered by the HP3561A Signal Analyser at 400 Hz. This compares with 250 Hz, in the CSU case. Recent work reported by Letchford et al (1992, Figure 8) indicates that for the case of the TTU model data obtained by Windtech, in cases of separated flow, the setup for the 1:50 scale model data would result in a minimum peak response ratio of 0.97 and in the 1:100 model scale scale situation, the corresponding figure would be 0.85. Similarly, the CSU 1:100 scale model setup would result in a minimum peak response ratio of 0.73, indicating considerably higher attenuation of the maximum peaks in cases of separated flow (such as obtained from tap 50101 between azimuths 180 to 270 degrees). The corresponding maximum peak response ratios are 0.99, .97 and 0.93 respectively. A study by Bienkiewicz et al (1992) of the surface flow pattern for the above case confirms that this flow is separated flow. On the other hand, the effect at tap 50209 between the same wind azimuths is a result of secondary separation. A region of reattached flow runs from the windward corner between the two tap locations.

These levels of attenuation of peaks account for a large part (possibly half) of the difference between wind tunnel and full-scale results. Furthermore, the corresponding results for these three cases indicate a definite relationship between the Reduced Velocity (normalised by the smaller horizontal dimension and the cut-off frequency) and the attenuation of the maximum peak pressures in cases of separated flows, even at high cut-off frequencies.

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