EFFECT OF UPWIND OBSTACLES AND METEOROLOGICAL TOWER STRUCTURE ON SENSOR MEASUREMENTS

by

Seong-Hee Shin, Robert N. Meroney
Ronald L. Ewald and David E. Neff

Fluid Mechanics and Wind Engineering Program
Department of Cival Engineering
Colorado State University
Fort Collins, Colorado 80523

Prepared for
6th U.S. Wind Engineering Conference
University of Houston, Texas
8-10 March 1989

December 1988

CEP88-89RNM-RLE-SHS-DEN-8

EFFECT OF UPWIND OBSTACLES AND METEOROLOGICAL TOWER STRUCTURE ON SENSOR MEASUREMENTS

Seong-Hee Shin, Robert N. Meroney
Ronald L. Ewald and David E. Neff *

ABSTRACT

A wind-tunnel measurement program was completed to evaluate the measurement errors at the main meteorological tower at the James A. Fitzpatrick Nuclear Power Station (Figure 1). The effects of the Niagara Mohawk Power Corporation Nine Mile Unit 2 coolong tower on the main tower sensors, and the effect of the main meteorological tower's location on representativeness were estimated using fluid modeling techniques about a 1:750 scale model. The effects of the main meteorological tower structure on its sensors were estimated using a 1:16 scale model of a typical section of the tower.

INTRODUCTION

The Nuclear Regulatory Commission requires that operating nuclear power stations maintain meteorological instrumentation capable of providing accurate atmospheric input information for emergency preparedness and these instrumentations meet accuracy criteria; hence, they recommend certain siting standards. In the event these standards are not met, they encourage plant operators to establish the actual errors or bias based on laboratory or field measurements. Meteorological towers at the Nine Mile Point and James A. Fitzpatrick (JAF) Nuclear Power Plants in Oswego County, New York, near Lake Ontario provide key data for emergency preparedness and routine operations. This paper summarizes the results of a wind-tunnel simulation of the reactor site along Lake Ontario to evaluate the influence of reactor buildings and cooling towers,tower location, and meteorological tower structure on data reliability.

EXPERIMENTAL CONFIGURATION

These wind-engineering tests were performed in two different wind tunnels in the Fluid Dynamics and Diffusion Laboratory at

---

* Civil Engineering Department, Colorado State University, Fort Collins, CO.

Colorado State University. The two tunnels used were the Industrial Aerodynamics Wind Tunnel and the Meteorological Wind Tunnel . Also, tests were performed on two different models. The first model was a 1:16 scale model of a section of the main meteorological tower and the second was a 1:750 site model of the test area.

A 1:16 scale model of a representative section of the main meteorological tower was made from plastic architectural modeling materials. This model represented a section of tower approximately 17 m (56 ft) high and included one instrumentation level near the middle (Figure 2). This model was used exclusively to determine the effects and errors that the tower itself caused on the instrumentation. Also, two different plastic boom arms were constructed to hold the laboratory velocity and direction measuring equipment. The first arm held the instruments in the same locations as the existing field boom, and the second arm held the instruments in a T-configuration to test some proposed locations (Figure 3). The second model consisted of 1:750 scale models of the site buildings and structures. Individual models were made of the Nine Mile Point (NMP) Unit 1 and Unit 2 buildings, the James A. Fitzpatrick (JAF) building, the JAF new service building, and the cooling tower. The deviation of the flow due to the presence of the structures actually occurs in the atmosphere, and the measurements performed in the presence of the model buildings were performed in order to account for such effects.

Task I measurements of site effects on the main meteorological tower location were conducted in both the Industrial Aerodynamics Wind Tunnel and the Meteorological Wind Tunnel. All of the neutral wind conditions were completed in the Industrial Aerodynamics Wind Tunnel while all of the stable and unstable flow conditions were completed in the Meteorological Wind Tunnel. For Task I the wind always came from 82°. Upwind, and throughout the area, chains were placed across the wind tunnel to simulate the general terrain roughness of the site.

Task II measurements of tower influence on instruments were made entirely in the Industrial Aerodynamics Wind Tunnel. The 1:16 tower model was mounted on the turntable at the end of the test section such that approach winds from 0° to 360° could be tested. Since this investigation was to determine effects caused by the tower structure, these tests were performed in a uniform but moderately turbulent approach flow instead of a boundary layer type approach flow.

INSTRUMENTATION AND DATA ACQUISITION

The range of velocities examined required the use of two different measurement systems. Mean velocities and local turbulence intensities for the neutral conditions were measured with a single hot-film Thermal Systems Inc. anemometer. The second system used was a two-wire cross-film (TSI 1241) anemometer. This probe was used for velocity measurements at the lower speeds run during the stable and unstable conditions. Output from the anemometer was fed to an on-line data aquisition system consisting of an IBM AT PC computer, disk unit, printer, plotter, and a Data Translation Inc. analog-to-digital card.

Approach wind angle measurements and deviations were measured two different ways. For the higher mean velocities , a wedge type pitot probe was used. This probe is designed such that it measures a zero pressure difference when pointed directly into the flow and a positive or negative pressure difference when the flow comes from one side or the other. The second method for determining wind angle, θ, was by using the output of the cross-film velocity probe.

A copper-constant thermocouple with a bead diameter of 0.07 mm was mounted to the side of the hot-film probes. An Omega Model DSS-199 digital thermometer connected to this thermocouple provided an analog signal directly proportional to temperature. This analog signal was digitized and recorded in an IBM AT computer.

TEST PROGRAM AND DATA

Most of the data contained_in this paper are expressed in terms of normalized mean velocities (U or V), local turbulence intensities (TI), wind angle deviations ($\Delta\theta$), absolute temperature (T), or temperature difference ($\Delta\theta$). Normalized mean velocity is a measured local velocity divided by the simultaneous reference velocity measured at the 1500 ft elevation located in the free-stream of the wind flow. Local Turbulence Intensity is the local standard deviation of velocity expressed as a percentage of the local mean velocity fot either the longitudinal component U or the lateral component V. $\Delta\theta$ is the local deviation in measured approach wind angle from the true wind angle in degrees. T is the measured temperatures at points above the model in °C. ΔT is the difference in temperature between two elevations for a given profile location. In this paper the lower or reference height is always selected as 10 m or 30 ft. For Task II an additional parameter called the velocity ratio (VR) is specified. This is simply the ratio of the measured wind speed to the true approach wind speed.

A few measurements were taken to one side of centerline during the setup of flow conditions for both the neutral and stratified flow situations. The profiles showed no variations greater than the expected random instrumentation deviations.

Stable flow situations have been considered dozens of times previously in the Meteorological Wind Tunnel. Many lateral variation checks showed no systematic or significant deviations; thus, check measurements of this type for this measurement series were limited. For the unstable flow situation Poreh and Cermak (1984) made lateral and longitudinal measurements to determine homogeneity. They used a similar method to that used in the current effort to produce the unstable flow. Consideration of temperature profiles at two downwind distances compared with lateral temperature measurements at ± 0.4 m (equivalent to 1000 ft NYPA prototype distance) displayed no systematic deviations.

Repeat runs were taken for many of the test cases, but not all conditions. Velocity profiles do not deviate by more than 0.03 normalized velocity magnitude, turbulence profiles generally repeat within 0.02, but a few points may differ by as much as 0.03 to 0.035.

DISCUSSION OF RESULTS

Each of the two measurement tasks are discussed separately below.

Task I: Quantification of the Effect of the Site's Cooling Tower on Meteorological Sensors on the Primary Meteorological Tower

Measurements were performed at two wind speeds at the site of the primary meteorological tower vis-a-vis the effect of the Niagra Mohawk cooling tower for a wind orientation of 82°. Wind speed, angle, turbulance and temperature deviations were measured.

During neutral stratification, perturbations in wind speed and wind direction were less than 12.1 percent of free stream and ± 0.50°, respectively. Turbulence levels decreased from 0.23 to 0.18 percent. Thus, the cooling tower did not significantly affect the shape of the profiles measured over the height of the tower. This result is consistent with the measurements of Kothari et al. (1979), which show that building wake effects in neutral flow may not persist as long as in stable flow and nearly disappear by x/H values near 10.0. Hence, no corrections to primary meteorological tower measurements associated with the cooling tower are necessary.

During the high speed stable stratification conditions, the cooling tower wake was evident at the primary meteorological tower site. At the lower wind speed (stronger stable stratification) the cooling tower wake appeared to effectively disappear before the meteorological tower site was reached. Apparently both mechanical turbulence and vortex wake effects were dampened by the stratification.

During unstable stratification conditions, the cooling tower affected the overall wind profiles slightly. For the lower wind speed unstable stratification conditions, insertion of the cooling tower caused velocity defects of about 8 percent; whereas at the higher speed velocity defects of 12 percent were detected. Wind angle deviations were generally below 5°.

Although the perturbations detected for the situation when the primary tower is directly in the wake of the cooling tower are significant, they will occur for only a very narrow wind direction segment. According to the measurements of Hansen and Cermak (1975) and Kothari et al. (1979), perturbations in the wake of structures embedded in a deep turbulent boundary layer reduce to less than 2 percent at lateral distances of XD, where D is a characteristic width of the object.

Table 1 has been constructed to summarize the fractional changes in mean velocity, temperature and turbulence caused by the Niagra Mohawk cooling tower for different anticipated field conditions when the wind blows directly from the cooling tower toward the meteorological tower.

Task II: Quantification of the Effect of the Meteorological Tower Structure on Sensor Measurements

Tests were performed for both the current instrument locations and new locations on a proposed boom (Figure 3) during neutral conditions. The initial tests were computed at three wind speeds for four different approach wind directions (67.5°, 90°, 112.5°, and 270°). These data are summarized in Table 2 for the current position. The data indicate that the effects caused by the structure on the instrumentation is essentially independent of wind speed.

A second group of data--Table 3 for the current boom position -- demonstrate the effects of the tower structure on the instrumentation for a full 360° are of approach wind conditions. From this data, two distinct areas of disturbance can be seen.

First, in the sector of winds from NNE to ESE, an area of large velocity defect and large turbulence increase is observed. Although the current and proposed boom locations vary somewhat, they both show velocity defects through this sector of as much as 35 to 38 percent, and turbulence levels that increase from a background level of about 1 or 2 percent to levels around 7 to 12 percent. Therefore, σ_θ changes can be on the order of factors from 3 to 12 times too high. The second disturbance region is found in the sector of winds from S to W. In this region a slight slowdown in the mean velocity of the order of 2 to 10 percent is observed, because as the flow approaches the tower from upwind it begins to slow down or stagnate before it is pushed out around the sides of the tower. This same effect causes a slight speedup of mean velocity at the instrument locations for SE and NW winds of about 3 percent as the wind moves out and around the tower. However, for these wind directions there is no measurable affect of the tower on the turbulence. An upwind set of instrumentation would eliminate turbulence errors and reduce velocity errors from the 35 percent range to less than 10 percent.

The third quantity measured during these tests was the deviation of measured wind angle from the true wind angle ($\Delta\theta$). Both the current and proposed boom locations did see some small deviations in measured wind angle, but these deviations were never more than ± 4.11° (which is within the NRC guidelines of ± 5°); therefore, wind angle deviations for Task II are considered to be minor and insignificant.

To adjust for the tower perturbations measured during Task II it is possible to construct a tabular correction function for mean velocities, turbulence, and wind direction, all of which could be related to the measured wind direction. Unfortunately, unless the field data were to be reduced and corrected on an instantaneous basis, this tabular correction function would not work very well.

Although the wind-tunnel tests for Task II were all performed under neutral conditions, the above discussion should apply equally well to both stable and unstable conditions. This would be true for two reasons. First, the phenomenon is strictly a mechanically induced effect of the tower and its members; and secondly, the distances involved (12 to 14 ft out from the tower) are too short for stability conditions to have any noticeable impact. In other words, it does not matter how a velocity or turbulence is generated before it reaches the tower, but once it impinges on the tower, the effect of the tower locally will be predictable.

REFERENCES

Binkowski, F. S., 1979, "A Semi-Emperical Theory for Turbulence in the Atmospheric Surface Layer," Atmos. Envir., Vol. 13, No. 2, pp. 247-253.

Freeman, D. L., Egami, R. T., Robinson, N. F. and Watson, J. G., 1986, "A Method for Propagating Measurement Uncertainties through Dispersion Models," J. of the Pollution Control Association, Vol. 36, No. 3, pp. 246-253.

Gifford, F. A., Jr., 1975, "Turbulent Diffusion Typing Schemes: A Review," Enviromental Research Laboratories, ATDL Report No. 75/2, or, 1976, Nuclear Safety, 17, No. 1, pp. 68-86.

Golder, D., 1972, "Relations Among Stability Parameters in the Surface Layer," Boundary-Layer Meteorol., Vol. 3, pp. 56ff.

Hansen, A. C. and Cermak, J. E., 1975, "Vortex-Containing Wakes of Surface Obstacles," FDDL Report CER75-76ACH-JEC16, Colorado State University, Fort Collins, Colorado.

Haugen, D. A., ed., 1973, "Workshop on Micrometeorology," American Meteorological Society, Boston, 392 pp.

Hunt, J. C. R. and Simpson, J. E., 1982, "Atmospheric Boundary Layers over Non- homogeneous Terrain," Engineering Meteorology (ed. E. Plate), Elsevier, New York, Ch. 7, pp. 269-318.

Kothari, K. M., Peterka, J. A. and Meroney, R. N., 1979, "Stably Stratified Building Wakes," Fluid Dynamics and Diffusion Laboratory, Colorado State University, Fort Collins, Colorado, CER78-79KMK-JAP-RNM65.

McRae, G. J. and Tilden, J. W., 1980, "A Sensitivity and Uncertainty Analysis of Urban Scale Air Pollution Models--Preliminary Steps," in Second Joint Conference on Applications of Air Pollution Meteorology, American Meteorological Society, Boston, MA.

Plate, E. J., 1971, "Aerodynamic Characteristics of Atmospheric Boundary Layers," US Atomic Energy Commission, TID-25465, 190 pp.

Poreh, M. and Cermak, J. E., 1984, "Wind Tunnel Simulation of Diffusion in a Convective Boundary Layer," Boundary Layer Meteorology, Vol. 30, pp. 431- 455.

Simpson, R. W. and Hanna, S. R., 1981, "A Review of Deterministic Urban Air Quality Models for Inert Gases," NOAA-TM-ERL-ARL-106, Silver spring, MD.

Snyder, W. HY., 1981, "Guideline for Fluid Modeling of Atmospheric Diffusion," United States Environmental Protection Agency Report EPA-600/8-81-009, 185 pp.

Veenhuizen, S. D. and Meroney, R. N., 1969, "Secondary Flow in a Boundary Layer," Project THEMIS Report No. 3, CER68-69DSV-RNM28, (also Paper 72WA/FE34, ASME Winter Annual Meeting, 1972).

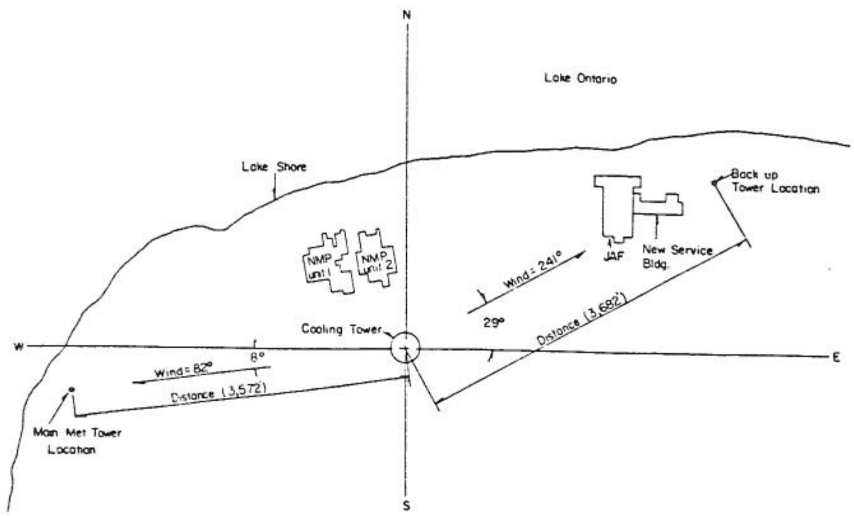

Figure 1. Site Map and Structure Locations

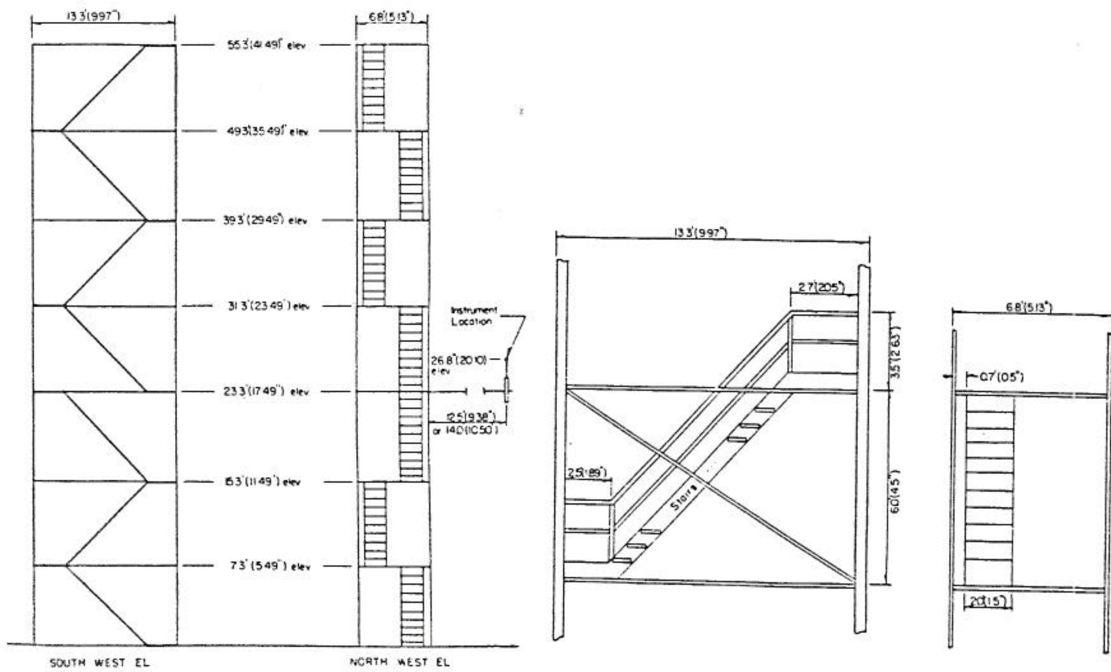

Figure 2. Primary Meteorological Tower Model, Dimension Drawings

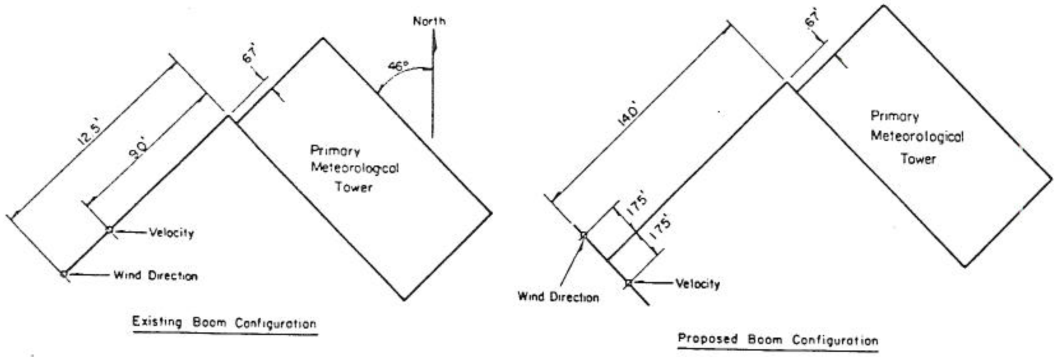

Figure 3. Existing and Proposed Instrument Boom Locations

Table 1. Task I - $(\bar{U})c$, $(\Delta T)c$, and $(TI)c$

Para-meter	Height (H)	Unstable Low Speed	Unstable High Speed	Neutral Low Speed	Neutral High Speed	Stable Low Speed	Stable High Speed
$(\bar{U})c$	30	-.066	-.105	.033	.121	.028	-.157
	100	-.079	-.121	.056	.052	.015	-.190
	200	-.027	-.098	-.046	.090	-.038	.009
(TI)c	30	-.025	-.010	-.032	-.051	-.077	-.118
	100	-.102	-.190	-.233	-.083	.192	3.724
	200	.144	.213	.033	-.016	-.500	2.743
$(\Delta T)c$	100	.109	-.206	x	x	.300	-.095
	200	.118	-.145	x	x	.105	.102

Note: All changes listed are fractional.
$(\bar{U})c = (\bar{U}_{CT} - U_R)/U_R$
$(\Delta T)c = (\Delta T_{CT} - \Delta T_R)/\Delta T_R$
where $\Delta T = T_h - T_{30}$,
$(TI)c = (TI_{CT} - TI_R)/TI_R$
Reference (R) Site Condition = 3 power plant buildings in place
Coolong Tower (CT) Site Condition = 3 power plant buildings and coolong tower in place

Table 2. Task II Data - Current Boom Position

	Boom Measurements at Current Position				
Approach Wind Direction	(a) Wind Tunnel Speed m/sec	(b) Measured Velocity m/sec	Turbulent Intensity % u'/u_∞	Velocity Ratio (b)/(a)	$\Delta\theta$(°)
67 1/2°	15.03	11.93	12.35	0.794	+3.74
67 1/2°	10.00	7.98	12.64	0.798	+4.10
67 1/2°	4.97	4.02	12.47	0.810	+3.74
90°	15.05	9.71	7.90	0.645	-0.83
90°	10.00	6.60	8.40	0.660	-0.83
90°	5.03	3.39	7.97	0.674	-0.25
112 1/2°	15.00	15.10	3.06	1.007	-1.51
112 1/2°	10.01	10.15	2.80	1.014	-1.22
112 1/2°	5.00	5.11	2.42	1.021	-1.22
270°	15.01	13.85	1.33	0.922	+1.12
270°	10.02	9.25	1.13	0.923	+1.48
270°	4.97	4.59	1.07	0.905	+1.48

Table 3. Task II Addendum Data - Current Boom Position

	Boom Measurements at Current Position				
Approach Wind Direction	(a) Wind Tunnel Speed, m/sec	(b) Measured Velocity m/sec	Turbulence Intensity % u'/u_∞	Velocity Ratio (b)/(a)	$\Delta\theta$(°)
0°	14.96	15.48	1.07	1.035	+1.00
22 1/2°	15.00	15.36	1.73	1.024	-0.08
45°	15.01	9.32	11.70	0.621	-0.22
67 1/2°	15.00	11.91	12.29	0.794	+3.06
90°	15.01	9.78	7.87	0.651	-1.27
112 1/2°	15.02	15.18	2.93	1.011	-2.53
135°	15.01	14.96	1.21	0.997	-1.99
157 1/2°	14.98	14.58	1.17	0.973	-3.75
180°	14.97	14.05	1.15	0.939	-4.11
202 1/2°	15.00	13.68	1.14	0.912	-2.31
225°	15.01	13.56	1.17	0.903	-2.02
247 1/2°	14.98	13.86	1.34	0.925	-1.05
270°	14.96	14.06	1.13	0.940	+0.46
292 1/2°	15.05	14.62	1.46	0.972	+1.72
315°	15.02	14.92	1.09	0.993	+1.68
337 1/2°	15.04	15.23	1.24	1.013	+1.50