Wind-Tunnel Simulation of Pedestrian-Level Wind in Los Angeles

Bruce R. White
University of California, Davis
U.S.A

1. OVERVIEW

This summary describes the methodology developed to address pedestrian-level winds within the South Coast Air Basin, a 6,000-square mile area that includes Orange County, most of Los Angeles and Riverside Counties. Working with the city of Los Angeles officials guidelines for wind-testing procedures, analysis, and report-data presentation were established. The assessment is accomplished through wind-tunnel testing that couples full-scale meteorological data to physical modeling data. The primary application of this evaluation process is in the environmental impact assessment of proposed buildings, industrial complexes, and other construction projects that may substantially alter pedestrian-level winds in public areas. To date, since 1990, fifteen different wind-tunnel studies have been carried out by the author using this method, and it has been well received by the city of Los Angeles planning officials.

2. WIND ENVIRONMENT IN LOS ANGELES

Winds in Los Angeles are monitored at several locations, including the Los Angeles International Airport. Data describing the speed, direction, and frequency of occurrence of wind at the Los Angeles International Airport were gathered hourly for 16 equally spaced wind directions during a six-year period from 1953 to 1958. Data from the airport is recognized as being the highest quality data available. When using long-term records, it is important to select data recorded at a weather station whose monitoring height was high enough above ground level so as to minimize the influence of surface-level effects. Also, long time periods are preferred (i.e., 5 to 10 years, or more if feasible), since unusual wind occurrences can be absorbed in the log-term statistics.

3. WIND EFFECTS OF TALL BUILDINGS

The frequency of occurrence, speed, and level of turbulence of winds at street level are important to the comfort and safety of pedestrians in urban areas. Tall buildings which rise above general development, may intercept the faster winds that flow higher above the ground. Ground-level winds can be significantly changed when a building, or group of buildings, divert a portion of the higher-level winds down the face of the building until that flow is either deflected or reaches pedestrian level. Because the diverted winds have higher speeds than those near the ground, the effects of those diverted winds can be substantial. High-rise buildings in and around downtown Los Angeles can rise many hundreds of feet above the lower buildings in the surrounding area, and thus present major obstacles to the winds that would otherwise flow freely over the city. Generally, as the heights of buildings in an area become more uniform (i.e., with further development), the ground-level effects of an individual tall building in the area are reduced.

4. WIND-TUNNEL TESTING

A 1:600 scaled model is generally used to test the prevailing winds. Typically as least two configurations are addressed in the analysis: i) the existing setting; and, ii) the existing setting plus the project. Winds speeds are generally measured at up to 50 representative locations in the test of the existing setting and the same locations in the test of the existing setting plus the project.

5. METHODOLOGY AND ASSUMPTIONS

For each surface wind-speed measurement made in the wind tunnel, it is desirable to estimate an associated full-scale wind speed frequency distribution. The determination of the full-scale wind distribution will, of course, depend upon the nature of the meteorological conditions at the site. For the present study, it was determined to use the full-scale mean wind sped exceeded 10% of the time from 8:00 a.m. to 7:00 p.m. The meteorological data used were originally acquired at the weather station at the Los Angeles Airport during the years 1953-1958 on an annual, hourly basis for 16 equally spaced wind directions. The measurements were taken hourly and averaged over one-minute and averaged over one-minute periods. Of the 16 measured wind direction, three primary wind directions comprised the greatest frequency of occurrence as well as the majority of strong wind occurrences. These wind directions were westerly, easterly, and northerly winds which had associated occurrence rates of 59%, 5% and 2% respectively, from 8:00 a.m. to 7:00 p.m. The remaining wind directions comprised the other 18% frequency of occurrence. Calm conditions occurred 16% of the time.

In order to determine whether or not equivalent wind speeds are acceptable at specific locations, it is necessary to establish a set of "comfort" criteria that defines wind speeds that are usually acceptable for specific pedestrian uses. The term "10% exceeded speed" is used in the criteria to account for the frequency with which winds occur. The 10% exceeded speed is the speed that is exceeded on day out of 10, or 10% of the time, from 8:00 a.m. to 7:00 p.m.

The wind intensity is defined in terms of the equivalent wind speed. This term denotes the wind speed averaged over an hour (hourly mean wind speed), modified to include the level of gustiness, or turbulence, expected on the site. The equivalent wind speed s calculated in the present context assumes and unaltered wind with an inherent turbulence intensity of 15% of the hourly mean wind-speed value. The turbulence intensity is defined as the root mean square of the instantaneous deviations from the value of the mean velocity, divided by the mean velocity value. When turbulence intensity as a street level point is greater that 15%, the mean velocity for that point is multiplied by two times the turbulence intensity plus 0.7 to create the equivalent wind speed for that point. This equation follows relationships developed by Hunt et al. (1976) and Jackson (1978) in which winds with different turbulence intensities were compared to each other for their effects on pedestrians.

For each of the major wind directions, the individual wind-speed value that the mean exceeded 10% of the time was determined from the meteorological data. The values of the 10% exceeded speeds were 20.7, 11.5, and 16.1 mph for northerly, easterly, and westerly winds, respectively. The 13 remaining untested wind directions had an average 10% exceeded wind speed of 13.8 mph, at a height of 59 feet above ground level.

The method used to estimate the full-scale 10% exceeded wind speed assumed the ratio of pedestrian-level wind speed to reference height speed (both in the wind tunnel) was equal to the same ratio in full scale. The reference height used corresponds to the height of the weather station at the Los Angeles International Airport (59 feet). The average of the measured wind-tunnel wind ratios for the three tested wind directions (at a given position and

setting) was assumed to be the mean wind ratio of the 13 untested wind directions. The justification for this procedure is that there is a symmetry-of-sorts of the wind flow around buildings and although the technique is not 100% accurate, it does provide a reasonable estimate of the average wind speed that would occur from the untested 13 wind directions. Thus, the weighted cumulative averaged pedestrian-level 10% exceeded wind speed calculations account for all wind directions.

The ratio of the reference height wind speed to the wind speed at pedestrian-level is calculated from the results of the wind-tunnel experiment for each major direction at each observation location. For each, the calculation procedure to determine a given percent exceeded wind speed (in the present case this is 10%) involves three steps. First, a pedestrian-level wind speed is selected. Second, the specific pedestrian-level wind speed is used to calculate the reference height wind speed for each wind speed component (using the ratios from the wind-tunnel experiment). Third, the meteorological data used to determine the percentage of time each of the reference level wind speeds is exceeded. The three steps are iterated, with changes in the pedestrian-level wind speed, until the percentage of the time the winds are exceeded equals the selected percentage of time, thus yielding the selected percent exceeded wind speed. The process may be repeated numerous times in 1% increments to develop pedestrian level wind speed frequency distributions.

For the present case, the 10% exceeded pedestrian-level wind speed is determined from wind-tunnel measurements made for the three wind directions. The wind-tunnel speed is scaled to the full-scale speed by use of the power-law relationship given by Davenport (1961). The airport meteorological data is used to find the distribution of speed as a function of time based on the wind-tunnel speed ratio. The airport meteorological data is adjusted to the appropriate α, power-law coefficient value which is set depending upon the local terrain of the test area; i.e., from airport conditions $\alpha = 0.2, \delta = 500$ feet and for downtown conditions $\alpha = 0.3, \delta = 1500$ feet.

The individual wind direction meteorological data is expressed as a cumulative frequency distribution which is reasonably well described by the relation, $N = \exp(k1 \log(S) + k2)$ where N is the number of hourly observations, or percent of total time, the wind speed exceed the value S. S is the wind speed of interest; i.e., 11 mph, and k1,k2 are empirical constants fit to the data. The cumulative full-scale frequency distribution of wind, at a height of 59 feet, is then calculated and the desired percent exceeded wind speed is mathematically described.

6. PRESENTATION OF RESULTS

The wind-tunnel test results are presented in table form as output from the computer program. Table I displays a typical output for three locations. The 10% exceeded pedestrian-level wind speed (mph) is calculated and shown after the location column. The appropriate criterion is listed in the next column to the right (it is adjustable depending upon the location and in this sample case set to 11 mph). Next, the wind-tunnel speed ratios and corresponding contributions are presented for the three tested wind directions (north, east and west) and the other column is the average of the three test cases that is used to account for the untested cases; which accounts for only 18% of all occurrences. The contributions indicated the weighting of each 10% exceeded pedestrian-level wind speed calculated. For example, for location 1, 89.7% of the 10.59 mph wind speed is contributed from the west prevailing wind direction. In this way, the major influencing wind directions can be

identified and the validity of not testing all wind directions can be determined; i.e., in location 1, only 0.8% of the 10.59 mph is estimated to be caused by the untested wind directions.

These data of Table I are from a proposed high-rise structure in the heart of downtown Los Angeles near the intersection of Seventh and Figueroa Streets. For the existing setting location 2 exceeds the 11-mph criterion 1.0% of the time resulting in 10% exceeded pedestrian level wind of 11.19 mph, with 95.5% contribution coming from the west wind direction. In the project settling location 2 has an 11.79 mph wind with 2% exceedance of the criterion. Location 1 appears as a 13.40 mph 10% exceeded wind speed with a 5.0% exceedance of the 11-mph criterion, with 93.4% of the exceedance being attributed to the west wind. In the existing setting there was an exceedance for Location I.

In this fashion, a detailed analysis of the future wind environment around a project can be analyzed locating critical areas and the specific wind directions and frequencies that would create the condition. In this manner, intelligent planning decisions may be made that are based on quantitative data and not subjective opinions.

The fifteen studies carried out to date have met with positive response from the city officials, primarily because the method judges each project in a consistent, non-subjective manner. Additionally, the magnitude of potential adverse impacts are specified.

7. INTERPRETATION OF RESULTS

A set of "comfort" criteria defines equivalent wind speeds that are usually acceptable for specific pedestrian uses. The term "10% exceeded speed" is used in these criteria to account for the frequency with which such "equivalent" winds occur. The city of Los Angeles officials have agreed to following for recent wind-tunnel studies carried out by the author: 10% exceeded speeds of 7 mph and less will be considered as comfortable for outdoor seating. Those 10% exceeded speed of 11 mph and less will be considered comfortable for standing and leisure walking, while those between 12 and 15 mph will be suitable for walking and other occasional uses. Ten percent exceeded speeds is excess of 15 mph will result in potentially uncomfortable pedestrian conditions. Ten percent exceeded speeds reaching or exceeding 36 mph create potential safety hazards for pedestrians. Currently, the city of Los Angeles Municipal Code does not provide legally binding criteria to be used in the evaluation of the effects of buildings on pedestrian-level winds, nor does a standard set of criteria exist.

The seating criterion of 7 mph equivalent wind speed not to be exceeded more than 10% of the time year round between 8 a.m. and 7 p.m. was based on the wind-speed seating criterion given by Penwarden (1973), Melbourne (1978), and Arens (1981). The interval time of interest was chosen when most of the population would be exposed to the wind. It was essentially an environmental quality decision based on the study of wind related complaints in shopping centers (Penwarden, 1973). Penwarden found that most complaints occurred where the limit of comfort (7 mph) was exceeded more than 10% of the time. The same also was found to be true for the 11-mph and 15-mph comfort criteria.

Additionally, Penwarden's suggestions for the onset of discomfort were based on mean speeds and did not contain effects of turbulence or gustiness in his assessment. This is precisely the reason the current method uses equivalent wind speeds instead of the mean speed. The equivalent wind speed incorporates the effects of turbulence to estimate what a mean wind speed with a 15% turbulence intensity (the unaltered value) would feel like or be equivalent to when turbulence effects are incorporated. This procedure follows the ideas of estimating equivalent wind speeds with variable levels of turbulence presented by Hunt et. al. (1976) in which winds of different turbulence intensities were compared to each other for their effects on pedestrians.

8. CONCLUSION

A general methodology in estimating full-scale pedestrian-level wind speed distribution is outlined. The analysis incorporates full-scale meteorological data as the basis for the estimate. The results are equivalent to having a complete set of probability distribution functions for each location point measured in the wind tunnel. This includes directional dependence as well as speeds.

This method has been useful to the city of Los Angeles planning officials who now can quantitatively identify problem wind areas knowing the magnitude of changes to an existing wind environment due to the presence of proposed structures.

9. REFERENCES

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Table I SAMPLE COMPUTER OUTPUT*

Location	10% Exc. ground speed (mph)	--Criterion-- speed (mph)	% time exc.		N	E	W	OTHER
Existing Setting								
1				RATIOS	0.8612	0.4250	0.8726	0.7196
	10.59			CONTRIB	9.0%	0.5%	89.7%	0.8%
		11	0.0%	CONTRIB	9.3%	0.5%	89.5%	0.8%
2				RATIOS	0.6802	0.4236	0.9368	0.6802
	11.19			CONTRIB	3.7%	0.4%	95.5%	0.5%
		11	1.0%	CONTRIB	3.6%	0.4%	95.5%	0.5%
3				RATIOS	0.7720	0.3856	0.6062	0.5879
	7.49	11	0.0%	CONTRIB	13.8%	1.1%	83.6%	1.4%
				CONTRIB	23.4%	1.2%	74.2%	1.2%
Existing Setting With Sample								
1				RATIOS	0.9758	0.3468	1.1148	0.8125
	13.40			CONTRIB	6.4%	0.0%	93.1%	0.5%
		11	5.0%	CONTRIB	7.7%	0.1%	91.4%	0.8%
2				RATIOS	0.7010	0.4656	0.9878	0.7181
	11.79			CONTRIB	3.4%	0.4%	95.7%	0.5%

		11	2.0%	CONTRIB	3.5%	0.5%	95.5%	0.5%
3				RATIOS	0.8510	0.2194	0.7462	0.6055
	9.12			CONTRIB	12.2%	0.0%	87.1%	0.7%
		11	0.0%	CONTRIB	15.6%	0.0%	83.7%	0.6%

* The comfort criterion is set at 11 mph.