DESIGN GUST WIND SPEEDS IN THE UNITED STATES[a]

Discussion by Emil Simiu,[3] Fellow, ASCE, and James J. Filliben[4]

The main result of the authors' work is Fig. 5, a map containing 50-year peak gust wind speeds specified for structural design purposes. Except for (1) the states of California, Oregon, and Washington; (2) areas affected by hurricanes; and (3) a few small special wind regions, that map specifies a wind speed of 90 mph (40 m/s) regardless of geographical location. The question arises whether the true 50-year peak gust speeds are indeed close to 90 mph (40 m/s) over that entire geographical area, or whether the map is in fact masking real differences among distinct extreme wind climates.

The contours of the 50-year map based on the authors' own calculations (Fig. 3) contain estimated speeds varying from 80 mph (35.8 m/s) in northern Minnesota and Wisconsin to 95 mph (42.5 m/s) in portions of Oklahoma and New Mexico. The difference between the largest and the smallest estimated speeds is almost 20%; if, as is done by the authors, we consider the difference in terms of the corresponding wind loading, the percentage is about 40%.

Assume, for the sake of argument, that the estimation methodology used by the authors to obtain the wind speed contours of Fig. 3 is correct. From Simiu et al. (1979) (henceforth referred to as SCF) it can be verified that, for almost 100 samples of average 32-year size in nonhurricane wind regions other than the states of California, Oregon, and Washington, the standard deviation of the sampling errors in the estimation of the 50-year peak gust speeds is about 5.5 mph (2.5 m/s). Since the authors report that the average size of their samples was 118, it follows that for their estimates the approximate corresponding standard deviation of the sampling errors is smaller by a factor of about $(32/118)^{1/2}$, that is, about 2.9 mph (1.3 m/s). We are interested in the probabilities of occurrence of deviations from the mean value $(35.8 + 42.5)/2 = 39.15$ m/s of $39.15 - 35.8 = 42.5 - 39.15 = 3.35$ m/s, that is, deviations equal to $3.35/1.3 = 2.6$ standard deviations of the sampling errors. Under the common assumption of normality, such probabilities are roughly 0.005. Given this low confidence level, the authors' assertion that the 50-year speeds are 40 m/s regardless of location is not tenable. Rather, on the basis of their own estimates, for certain areas the speeds should be lower, and for others they should be higher, than 40 m/s.

The authors departed from good extreme wind climatological practice established in the United States for decades by not documenting their estimates with supporting data and information. In the absence of proper documentation, the scrutiny needed to validate extreme wind speed estimates—without which such estimates cannot be responsibly accepted for public use—is difficult or impossible. The reason invoked by the authors for not following established practice by providing, in print and/or in electronic form, listings of the data, anemometer elevations, terrain exposures, and recording dates is that "the digital database in ASCII is well over 100 MB in size," even though the capacity of one CD ROM is about 600 MB. (The total number of data used by the authors was of the order of 500 stations times an average sample size of 25 years and could fit comfortably even in a small printed report.)

Good extreme wind climatological practice requires that data sets used for statistical estimates satisfy basic requirements with respect to (1) micrometeorological homogeneity, (2) climatological consistency, and (3) statistical independence.

Micrometeorological Homogeneity. For the statistical analyses to yield credible results, the data in any one sample should be micrometeorologically homogeneous, meaning that the data should be reduced to the same elevation and to the same type of terrain exposure. The authors indicate, however, that they used data uncorrected for terrain roughness effects. One justification offered by the authors is that peak thunderstorm gusts "are likely to occur near the outflow, where upwind roughness may not represent an appropriate correction." In fact there are strong indications that retardation of thunderstorm winds near the ground is similar to retardation in extratropical storm winds (for an example, see Simiu and Scanlan 1996, p. 80). A conventional correction for thunderstorm winds is, therefore, better than no correction at all. Besides, the argument that thunderstorm winds may have different retardation characteristics cannot justify the authors' failure to use exposure corrections for *any* wind speeds: in fact most extreme winds in extratropical regions of the United States are not due to thunderstorms. If the authors' argument were carried to its logical conclusion, wind tunnel tests for buildings with exposure other than open terrain would be conducted without attempting to simulate terrain roughness. This argument is not accepted in wind tunnel simulations. The authors offer a second justification for disregarding roughness effects: "the project was conducted with limited resources, which did not permit exposures to be determined. . . . This is an appropriate area for future research." Since the authors were aware that uncorrected data contaminated their records in a manner they were unable to assess, they should have refrained from using those data, or they should not have proposed a map for a national standard on the basis that it is "an appropriate area for future research."

Climatological Consistency. Climatological conditions depend upon (among other factors) geographical features, including elevation above sea level and position with respect to orographic obstacles.

For example, Boise, Idaho, is situated at about *820 m* elevation and stretches southwest from the foothills of the Boise Mountains, which rise 1500–1800 m above sea level in about 13 km. On the other hand, Pocatello, Idaho, is situated at an elevation of about *1400 m* above sea level; a desert extends to the west, and to the east the ground level rises steadily towards the crests of the Continental Divide. [See Local Climatological Data (LCD) Annual Summaries.] Extreme yearly winds from the west or southwest occur on average 8 years out of 10 in Pocatello, but only half as frequently in Boise (SCF). Fastest-mile winds over 60 mph (27 m/s) occurred on average about once in *40 years* in Boise, and about once in *5 years* in Pocatello; the highest fastest-mile winds that occurred in Boise in almost *80 years* were *62 mph* (28 m/s), and those that occurred in Pocatello in less than *40 years* were *72 mph* (32 m/s) (see LCD and SCF). The above information supports the view that there are significant differences between the wind climates of Boise and Pocatello. Creating a superstation including both stations would be inconsistent from a climatological viewpoint and would result in a record representative of neither the Boise nor the Pocatello extreme wind climate. This example illustrates the pitfalls of the "superstation" approach. If not used with great care it can produce incorrect information.

---

[a] February 1998, Vol. 124, No. 2, by Jon A. Peterka and Sohban Shahid (Paper 11627).

[3] NIST Fellow, Building and Fire Research Lab., National Institute of Standards and Technology, Gaithersburg, MD 20899.

[4] Math. Statistician, Information Technology Lab., National Institute of Standards and Technology, Gaithersburg, MD.

Consider a second example. The estimated 50-yr peak gust speeds are *76 mph* (34 m/s) for Denver, Colorado [with an estimated standard deviation of the sampling errors, or for short, "sdse," of 3.8 mph (1.7 m/s)]; *97 mph* (43 m/s) for Burlington, Iowa [sdse of 7.7 mph (3.4 m/s)]; *97 mph* (43 m/s) for Des Moines, Iowa [sdse of 6.5 mph (2.9 m/s)]; and *101 mph* (45 m/s) for Sioux City, Iowa [sdse of 6.2 mph (2.8 m/s)] [see SCF and, for the transformation of fastest-mile speeds to peak gust speeds, ASCE (1993)]. The differences between the geographical features characterizing Denver on the one hand and Burlington, Des Moines, and Sioux City on the other are obvious; the reader is referred to the LCD annual summaries for comments on the corresponding differences from a meteorological standpoint. There is no legitimate physical or statistical reason to ascribe identical extreme wind climates to Denver and the three Iowa sites just listed, as the authors have done in their Fig. 5. On the other hand, based on the respective wind speed statistics and the fact that orographic influences are relatively minor, one might legitimately assume that Burlington, Des Moines, and Sioux City have rather similar wind climates. The reader can verify by checking the dates on which annual extreme wind speeds occurred at the three Iowa sites (see SCF) that about 80% or more of those wind speeds were due to independent storm events, that is, to storms that did not affect more than one of the three sites. Note that if, for standardization purposes, one adopted 50-year peak gusts of 100 mph (45 m/s) for the three Iowa sites and 80 mph (36 m/s) for Denver, the ratio between the respective 50-year wind loads would be 1.56, as opposed to unity, as in Fig. 5. In accordance with current practice, Fig. 5 is unnecessarily onerous for Denver and insufficiently safe for Iowa.

Consider now a third example. Estimated fastest-mile 50-yr speeds for inland sites in Virginia (Lynchburg and Richmond) are *57 mph* (25 m/s) and *60 mph* (27 m/s), respectively [sdse of 4 mph (1.8 m/s) for both stations], whereas for Nebraska (North Platte, Omaha, and Valentine) they are *80 mph* (36 m/s), *83 mph* (37 m/s), and *84 mph* (38 m/s), respectively, with sdse's of 4 mph (1.8 m/s), 6 mph (2.7 m/s), and 6 mph (2.7 m/s), respectively. Adopting 50-year fastest-mile speeds of, say, 82 mph (37 m/s) for Nebraska and 60 mph (27 m/s) for Virginia, the ratio between the respective 50-year wind loads would be 2.0. If one adopted 50-year peak gust speeds of $1.2 \times 82 \cong 100$ mph (45 m/s) for Nebraska and 80 mph (36 m/s) for Virginia, the ratio of the respective wind loads would be 1.56, rather than unity, as in Fig. 5.

The reader can verify by consulting SCF that similar significant differences are evident among the wind climates of many other groups of sites. Such differences cannot routinely be ascribed to sampling errors. Ignoring their reality is detrimental to the integrity of the design process.

As mentioned earlier, the authors did not document how they combined specific records to create their superstations. It is clear from what was noted so far that a poor choice of combinations can result in misleading estimates.

Statistical Independence. The issue of the procedure used by the authors to test independence of data sets recorded at different stations merits discussion. The authors report that data sets taken at different stations exhibited relatively small mutual correlations. However, it should be noted that their data consisted of peak gusts. Peak gusts have great variability and are poorly correlated spatially at distances exceeding typical lateral turbulence scales; in other words, the gustiness affects the records as a form of noise. Even peak gust records taken at stations not more than a few hundred meters apart can exhibit relatively poor correlations. For this reason, the correlation tests used by the authors are not necessarily an indication that the respective data are mutually independent, as is required for the validity of the extreme values theory used in the paper.

That estimates presented in the paper are inadequate is demonstrated by the following results reported in Figs. 3 and 4. According to Fig. 3, the estimated 50-year peak gust in northwest Wyoming is 85 mph (38 m/s). Though one would expect the estimated 100-year peak gust speed to be higher, according to Fig. 4 it is only 80 mph (36 m/s). The estimated 200-year peak gust speed of Fig. 4 is 85 mph (38 mph), i.e., the same as the 50-year estimate. These results are aberrant. Such results cannot be attributed to sampling errors, since the same data set is used for the estimates corresponding to all three mean return periods.

The relation between estimates corresponding to different mean return periods is dealt with summarily in Fig. 5, which implies a coefficient of variation of the wind speed population in the conterminous U.S. of almost 20%. In reality the coefficient of variation is a function of geographical location. A 20% value for extratropical storm regions is untypically high (SCF) and for most locations may result in unrealistically large estimates of speeds with higher mean return periods.

To recapitulate, (1) data sets analyzed by the authors were contaminated by meteorologically inhomogeneous data, (2) the authors consolidated stations into superstations in a manner that, judging from Fig. 5, masks real differences among extreme wind climates, and (3) the theory of extreme values was applied by the authors to data sets that may exhibit poor correlations on account of the spatial variability of the wind gustiness, rather than being independent.

A map of extreme wind speeds included in a national standard affects the safety and economy of hundreds of billions of dollars worth of buildings and other structures. For this reason the discussers believe that efforts are in order to develop a wind map more realistic than Fig. 5. They trust that their comments will help to promote such efforts, and wish to thank Peterka and Sahid for the opportunity to discuss this issue.

Closure by J. A. Peterka[5] and S. Shahid[6]

The following responses are offered to the discussion.

1. The discussers state that there are deviations in the 50-year wind map contours of Fig. 3 of 2.6 standard deviations, which are outside the likely range expected.

One must be careful in interpreting data near the edges of a contour map, since subtle gradients within the region may distort edge effects (despite our use of the same contour routine used for national weather maps). For this response, we have formed two superstations from the area north of the 85 mph (38 m/s) contour in the Great Lakes area. One was composed of 9 stations with 177 station years east of Lake Michigan and the other was composed of 9 stations west of Lake Michigan with 188 station years of data. The 50-year speeds from these two superstations were 86 and 83 mph (38 and 37 m/s), respectively. Thus the lowest value on the map might be given as 83 mph (37 m/s). Using the value of sampling error calculated in this study for peak gusts (the discussers used fastest mile data instead of peak gusts analyzed in this study), the sampling error for the 50-year map is about 3.4 mph (1.5 m/s) (Table 2). The mean as determined from this study is 90 mph (40 m/s). The extremes are thus (95-90)/3.4 = 1.47 and (90-83)/3.4 = 2.06. These extremes represent, using a normal

---

[5] Prof., Fluid Mech. and Wind Engrg. Program, Dept. of Civ. Engrg., Colorado State Univ., Foothills Campus, Fort Collins, CO 80523.

[6] Grad. Res. Asst., Fluid Mech. and Wind Engrg. Program, Dept. of Civ. Engrg., Colorado State Univ., Foothills Campus, Fort Collins, CO.

distribution, a probability of 0.09; that is, about 9% of the area might be expected to fall outside these limits. Without calculating areas from the map of Fig. 3, it appears that the results are reasonably within expected limits. In fact, it appears that the areas are not far from the lower probability calculated by the discussers.

2. The discussers criticize the writers for not making the data set more available.

At the time the study was performed, the files of more than 100 MB could be contained on the Colorado State University mainframe hard disks for only a limited time, due to limits in capacity, and transfer of this volume of data was a significant task. Since that time, with the availability of cheaper volume storage, the data have been transferred to a CD ROM and the data has for some time resided at the National Climatic Data Center (NCDC), which, in our understanding, is trying to find a method for making the data available. The writers are not funded to become a repository or distributor of large meteorological data sets, a task better performed by NCDC. The data set has been made available at the writers personal expense to researchers who requested it.

3. With respect to micrometeorological homogeneity, the discussers are concerned that the data were not corrected for exposure, claiming that the data should not have been used at all before some correction, and stating that some correction is better than none.

This issue requires several responses. First, no data set used for a national wind load map has ever been corrected for exposure, including data used for the previous map (Simiu et al. 1979). Second, there is no acceptable model available even for the "conventional" correction suggested by the discussers. Even anemometers that are "well exposed" at airports exist in a region of nonequilibrium wind flow where the turbulence, and hence gust structure, is changing with distance at a rate that is different from that of the mean flow. Furthermore, the mean velocity correction is not always well known for these boundary-layer transition regions. For example, in preparing an anemometer siting guide for the FAA ("Siting guidelines" 1989), the senior writer performed boundary-layer wind-tunnel tests for wakes of forests to obtain corrections for mean velocity downwind from forests for straight line winds. Corrections were found to apply to even well-exposed airport anemometers.

The writers strongly disagree that a "conventional" exposure correction is better than no correction. There are many strong wind events in the United States caused by thunderstorm outflows. Where these originate on the airport (and for some microbursts may represent stronger measurements in the record), no correction is appropriate and a "conventional" correction that artificially increases these speeds would not be appropriate. The records themselves do not tell whether a wind speed occurred from a straight line wind or from a thunderstorm outflow, nor the distance of the outflow source from the anemometer location.

Corrections to any wind data set for upwind roughness represents a research project significantly larger than the one represented in this paper. In addition to issues such as equilibrium, it may be difficult or impossible to reconstruct the upwind roughness history for many sites over a 30 year history. This research would be a welcome addition to our knowledge base, but lack of this correction should not be used as an excuse to not use the improved knowledge of wind speeds represented by the paper.

Use of uncorrected wind data in the wind map is not at all comparable to performing boundary-layer wind-tunnel tests for wind loads on buildings without consideration of upwind roughness exposure at the building site. Since many, if not most, of the stations in this project are at airports, they represent as reasonable an approximation to an open-country exposure as we can expect for a data source. Building project sites, however, are mostly in city centers or suburban areas where the approach boundary layer characteristics are not representative of open country.

4. With respect to climatological consistency, the discussers raise concerns based on two issues—(1) combining stations with different settings, citing as examples stations in Idaho, and (2) assigning of a 90 mph (40 m/s) 50-year speed to stations that individually have values above or below that value.

With respect to (1), the lack of good station coverage in western states was pointed out in the paper. The examination of both individual stations *and* superstations, some stations of which might not represent identical climatological conditions, led to the conclusion that 90 mph is a safe design speed throughout the area even if some areas might have lower speeds. As an example, stations in eastern Washington and in the Central Valley in California, singly and as superstations, might support a 50-year speed lower than 85 mph. However, there are insufficient stations to permit the boundary of these lower speeds to be defined, and thus a decision was made to keep those areas within the 85 mph zone. Even in areas of inhomogeneous terrain, sampling errors still exist, and efforts, where appropriate, to reduce the impact of these errors is needed. The writers believe their decisions about speeds in these areas incorporates such consideration.

With respect to (2), the discussers carefully selected stations with high or low predicted speeds to show that the map is low or high in selected regions. Their examples, in fact, demonstrate the benefit of superstations. In virtually any region, individual stations in a superstation may show high or low speeds by the random processes at work. In a 20–30 year record, it is possible to have stations that have had an extended period without (or with) high speeds. Fig. 8 of Peterka (1992) shows the range of predicted fastest mile speeds for 377 stations with 25 years of digitally generated random speeds having an identical Type I distribution (along with a similar distribution from actual stations). The 29 actual stations in Fig. 8 are mainly in Illinois, Indiana, and Ohio. Predicted speeds range from about 60 to 90 mph (27–40 m/s). This variability for both synthetic and real stations is due entirely to chance, and is the reason the superstation concept was developed.

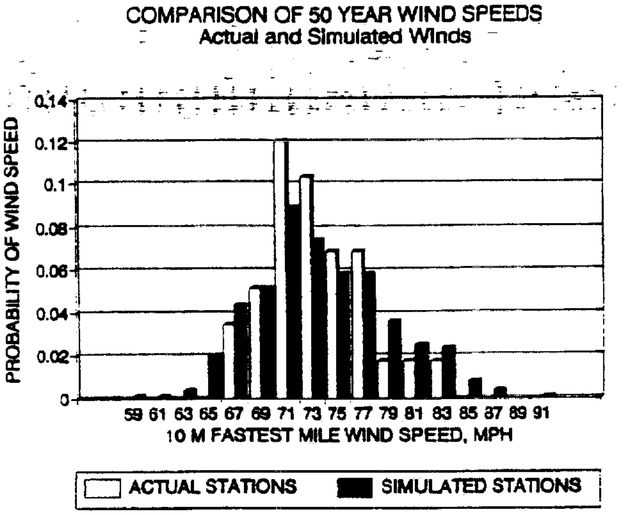

FIG. 8. Comparison of 50-Year Winds from 25-Year-Long Records from 29 Real and 377 Synthesized Stations

5. With respect to statistical independence, the discussers are concerned that the demonstrated statistical independence is based on turbulence in the wind, and independence of the underlying mean is not demonstrated.

First, it is not clear that independence of the underlying mean is required, only that independence of the event important for design, the peak speed, is achieved. However, we do not need to argue the point of independence of the mean, because we believe that there is in fact such independence. The issue of underlying mean is discussed on page 208 of the paper. As stated in the paper, because few peaks within a superstation were measured on the same day, and because those that were measured on the same day were often separated by stations not measuring a peak on that day, the statistical independence of the mean was established.

6. The discussers argue that the analysis is invalid because of inconsistencies noted in northwest Wyoming in Figs. 3 and 4.

These inconsistencies are rooted in the fact that there is a very low density of stations in the west, particularly in this area. This low density, coupled with the particular smoothing properties of the contour program used, produces the inconsistencies noted by the discussers. We used the same contour program used to plot contours for the U.S. daily weather maps. However, we suspect that any contour program would have difficulty with the low-density of stations in this region. We believe that this has no bearing on the validity of our analysis.

7. The discussers argue that the variation of speed with return period in Fig. 5 implies a coefficient of variation of "almost 20%" in the wind speed population.

We do not know how they calculated this value. We do not make such a claim, and do not believe that Fig. 5 implies that value. The rate of increase of extratropical wind speed with return period (100-year speed divided by 50-year speed = 1.07) is almost identical to that quoted in earlier versions of the national wind load standard, which is based on the analysis of Simiu et al. (1979).

The writers believe that the analysis contained in this paper represents a step forward in refinement of our understanding of design level wind speeds, and represents a safe and proper design guideline. The writers also believe that further research into the characteristics of extratropical extreme wind speeds may be useful. In particular, analysis of hourly data, while suffering significant defects for extreme wind prediction, might permit additional station density to be obtained in areas of low station density. The recent appearance of a large number of automated weather stations, many in previously low station density areas, may be of significant value to future analysis.

APPENDIX. REFERENCE

"Siting guidelines for low level windshear alert system (LLWAS) remote facilities." (1989). *Order 6560.21A*, Federal Aviation Administration (FAA), Department of Transportation, Washington, D.C.