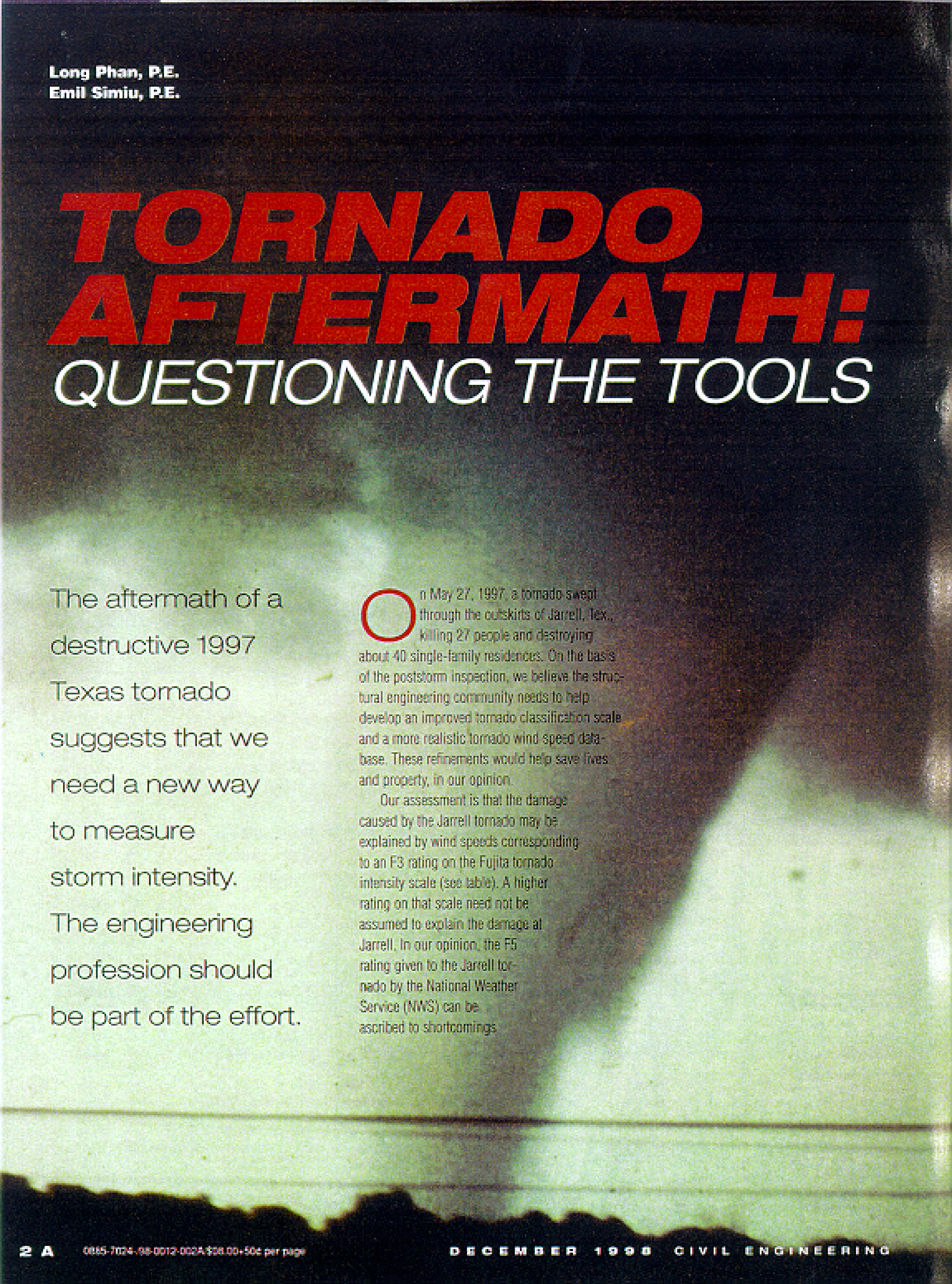
**Long Phan, P.E.**
**Emil Simiu, P.E.**

# TORNADO AFTERMATH: QUESTIONING THE TOOLS



The aftermath of a destructive 1997 Texas tornado suggests that we need a new way to measure storm intensity. The engineering profession should be part of the effort.

On May 27, 1997, a tornado swept through the outskirts of Jarrell, Tex., killing 27 people and destroying about 40 single-family residences. On the basis of the poststorm inspection, we believe the structural engineering community needs to help develop an improved tornado classification scale and a more realistic tornado wind speed database. These refinements would help save lives and property, in our opinion.

Our assessment is that the damage caused by the Jarrell tornado may be explained by wind speeds corresponding to an F3 rating on the Fujita tornado intensity scale (see table). A higher rating on that scale need not be assumed to explain the damage at Jarrell. In our opinion, the F5 rating given to the Jarrell tornado by the National Weather Service (NWS) can be ascribed to shortcomings


0885-7024-/98-0012-002A/$8.00+50¢ per page

of the Fujita tornado intensity scale.

The Office of the Federal Coordinator for Meteorological Services and Supporting Research, part of the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce, coordinated the inspection.

## THE TORNADO DETAILS

At 12:54 P.M. central daylight time on May 27, 1997, the NOAA Storm Prediction Center in Norman, Okla., issued a tornado watch indicating that tornadoes were possible in areas from east Texas to western Louisiana. At 3:30 P.M. NWS in Austin/San Antonio issued a tornado warning effective until 4:30 P.M. for south central Texas and Williamson County indicating that at 3:25 P.M. a tornadic thunderstorm was about 8 km west of Jarrell moving southeast at 1.6 km/h. Jarrell, population 410, is in Williamson County north of Austin.

Shortly before 3:40 P.M., tornado sirens alerted Jarrell residents of tornado sightings. Shortly before 3:45 P.M., the tornado first struck areas of Bell County and then crossed into Williamson County, where it destroyed structures in Jarrell and caused the 27 deaths. Witnesses estimated that its forward motion speed was between 8 and 16 km/h.

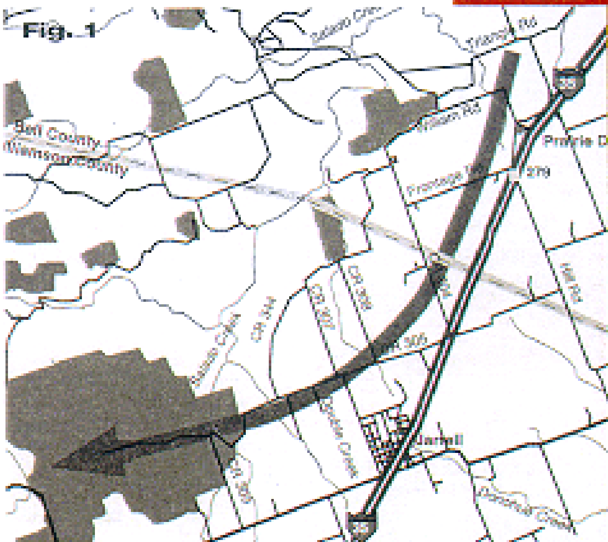
The Office of the Federal Coordinator for Meteorological Services and Supporting Research assembled the poststorm survey team, which included author Long Phan of the National Institute of Standards and Technology and Brian E. Peters of NWS. We conducted ground surveys on May 29 and June 1 and participated in two aerial surveys with the Texas Wing Civil Air Patrol station in Waco: one on May 30 using a fixed-wing aircraft flying at between 760 and 910 m and a second on May 31 using a helicopter flying at 150 to 300 m. We used a commercial global positioning system to obtain the coordinates defining the tornado path (Fig. 1).

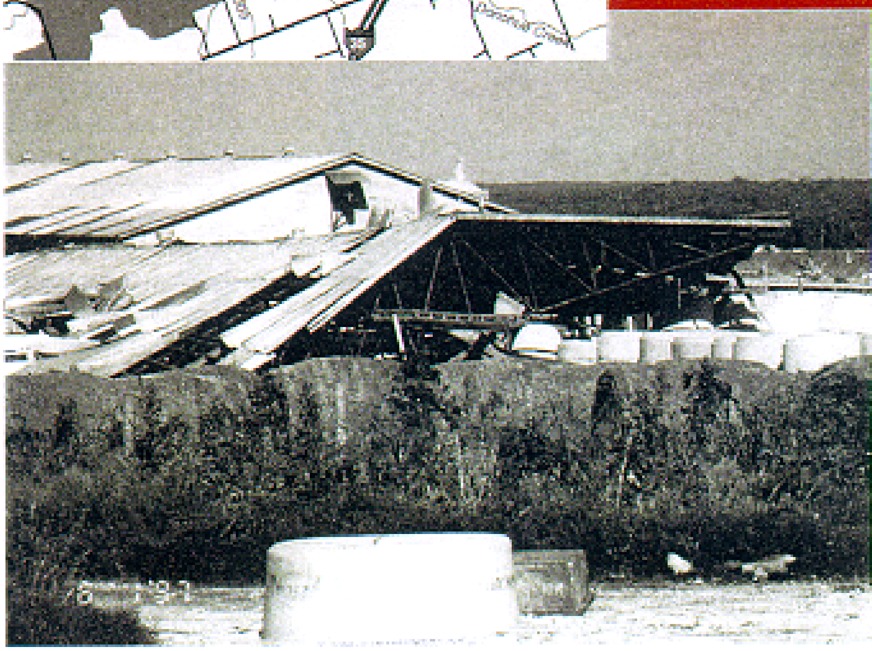
## DAMAGE OBSERVATIONS

Damage in Bell County was limited to trees and the roofs of a few residences. The tornado then crossed the county line into Williamson County, leaving strips of scoured asphalt surface as it crossed roads. The top layer of the asphalt pavement was about 20 mm thick. We ascribe the scouring to differences between the atmospheric pressure of pockets of air trapped underneath the asphalt and the lower atmospheric pressure at the tornado center.

The next structural damage along the tornado path occurred at the corner of two county roads in Williamson County, where a culvert plant collapsed in place. The plant was of light steel frame construction with nonreinforced masonry and steel tube columns supporting gable roof trusses of steel pipe. The steel tube columns were cast into a concrete mat foundation on grade. The roofing, supported by wood purlins, consisted of corrugated sheet metal. An identical plant approximately 15 m away from the collapsed culvert plant, along with

Fig. 1



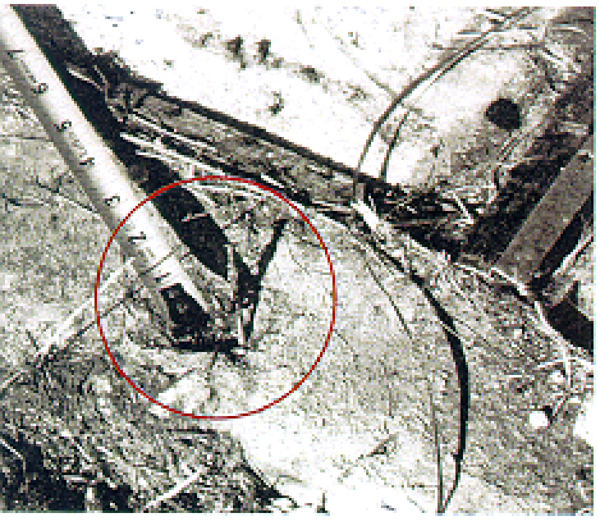
Engineers tracked the path of the May 27, 1997, tornado near Jarrell, Tex., using GPS. The tornado destroyed 40 single-family, wood-framed homes built on slabs, like those above, and killed 27 people. In Williamson County, the twister caused a light steel-framed culvert plant to collapse, while an adjacent, similar plant sustained only minimal damage (below).

surrounding structures, suffered only minimal damage. A mobile home used as an office was hit by a conventional "2 x 4" timber member 1.2 m long, but the missile did not penetrate the trailer. Another mobile home about 150 m north-northwest of the plant had only very minor damage. Its occupants fled to a house that was in the center of the damage path, where they were killed.

As the tornado continued its track south-southwestward, it destroyed a barn just southwest of the culvert plant and just north of a subdivision in Jarrell. The tornado then moved through the subdivision and the surrounding areas, where the destructive path widened to its maximum of 1.2 km and the tornado became most deadly.

The damaged structures were mainly single-family wood-frame houses of typical slab-on-grade construction built over the past 15 years or so. Because they were built on limestone bedrock, most had no basements or underground shelters. The tornado swept the houses completely off their concrete slabs. Inspections of the concrete slab-on-grade foundations showed that, in many cases, even the sill plates connecting the wood frames to the concrete slab-on-grade foundations had been blown away. There was evidence that these plates had been nailed to the foundations.

The Council of American Building Officials' code for single-family and two-family dwellings and other nationally recognized model codes require that sill plates of exterior walls for wood-frame construction be anchored to the foundation by anchor bolts not more than 1.83 m apart. The team found no evidence of anchor bolts. However, Williamson County has not adopted a building code, even though Jarrell was also hit by a tornado on May 17, 1989.



Engineers found evidence that sill plates were connected to concrete foundations by nails rather than the anchor bolts that many national building codes mandate.

## FUJITA TORNADO INTENSITY SCALE

| Category | Definition/Effects |
|---|---|
| F0 | Approximate wind speeds 18–32 m/s: Light damage. Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged. |
| F1 | Approximate wind speeds 33–50 m/s: Moderate damage. Lower limit is the beginning of hurricane wind speed; surfaces peeled off roofs; peel surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads. |
| F2 | Approximate wind speeds 51–70 m/s: Considerable damage. Roofs torn off frame houses; mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; missiles made of light objects. |
| F3 | Approximate wind speeds 71–92 m/s: Severe damage. Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forests uprooted; heavy cars lifted off ground and thrown. |
| F4 | Approximate wind speeds 93–116 m/s: Widespread devastation. Well-constructed houses leveled; structures with weak foundations displaced considerable distances; cars thrown and large objects made into missiles. |
| F5 | Approximate wind speeds 117–142 m/s: Strong frame houses lifted off foundations and carried considerable distances before disintegrating; automobile-sized missiles thrown distances in excess of 100 m; trees debarked. |

Source: National Post-storm Data Acquisition Plan, Office of the Federal Coordinator for Meteorological Services and Supporting Research, National Oceanic and Atmospheric Administration.

### MAXIMUM INTENSITY

The Jarrell tornado offers an opportunity to assess a subjective tornado intensity estimate based on Fujita scale damage descriptions. We made use of a structural engineering approach in our analysis.

The basic peak gust wind speed specified in the standard ANSI/ASCE 7-95 (*Minimum Design Loads for Buildings and Other Structures* [ASCE, 1995]) for the design of buildings in central Texas is 40 m/s. Building designs for central Texas before 1995 should be roughly compatible with this basic speed. Design and construction practices for buildings such as those destroyed by the Jarrell tornado are normally based on experience and judgment rather than formal engineering calculations. When they are sound, such practices are consistent with the requirement that buildings be capable of withstanding wind speeds higher than the basic design wind speed, with a safety margin with respect to wind loading of at most 1.5 to 2. It is reasonable to assume that in areas with a 40 m/s basic design wind speed buildings would collapse under winds loads roughly twice as large as the loads induced by the 40 m/s speed.

It follows from the proportionality of the wind loads with the square of the wind speeds that those buildings would be expected to collapse under wind speeds in excess of 40 m/s x $\sqrt{2}$, that is, about 56.6 m/s. This expectation would be even stronger for wind speeds corresponding to wind loads three times as large as those induced by the 40 m/s speed (i.e., 69 m/s wind speeds). Such winds would leave no buildings standing, especially if the construction were mediocre or poor, as appears to have been the case for buildings destroyed by the Jarrell tornado.

Speeds assigned to F3 tornadoes in the Fujita classification are about 71 to 92 m/s. For a building to resist such speeds, the wind load safety margin would have to be about 3.1 to 5.3. There is no reason to believe that any of the buildings destroyed by the Jarrell tornado were that strong. We note that 90 m/s wind speeds, which in the Fujita classification are associated with F3 tornadoes, would probably destroy residential homes not only in a 40 m/s basic design wind speed zone, but also in hurricane-prone areas with 63 m/s basic design wind speeds.

### SUMMING UP

Our conclusions are as follows:

- The strongest damage caused by the Jarrell tornado can be explained by wind speeds corresponding to an F3 rating (i.e., 71 to 92 m/s).

An F4 rating—or the F5 rating officially issued by NWS—need not be assumed to explain the observed damage.

- The Fujita tornado intensity scale has two major shortcomings that can lead to misclassification of tornadoes by nonengineers:

1) The scale does not reflect the dependence of the tornado wind speeds causing various types of damage on the design wind speed specified for a zone. For example, a tornado wind speed that tears off the roofs of well-constructed houses may be assumed to be larger by a factor of roughly 1.6 for zones in which the design wind speed is 63 m/s than for zones where the design wind speed is 40 m/s. Damage that in a 63 m/s zone could be attributed to an F5 tornado could be explained in a 40 m/s zone by F3 tornado winds.

2) The damage descriptions in the Fujita scale include the terms "well-constructed houses" and "strong frame houses." Nonengineers normally cannot be expected to ascertain whether or not houses destroyed by tornadoes were well constructed or strong.

These conclusions are significant for a variety of reasons:

- Misclassification corrupts the database used to set criteria for structures whose performance must be unaffected by strong tornadoes.
- Since even an F3 tornado can flatten most residential buildings, in our opinion NWS should consider revising its safety recommendations. At present, these assume that almost all tornadoes, including F4 events, are survivable.
- Ascribing failures to unrealistically high wind speeds when the actual speeds are in fact lower discourages the application and enforcement of design standards. Such standards, including ANSI/ASCE 7-95, can reduce the loss of life and property caused by most tornadoes.
- A stronger contribution from the structural engineering profession to efforts aimed at assessing tornado wind could help protect the public from tornado-induced losses.

We believe it's time to change the tornado intensity scale. Our recommendations are listed in the sidebar. ▼

Long Phan, P.E., M.ASCE, is a research structural engineer, and Emil Simiu, P.E., F.ASCE, is a NIST fellow at the Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, Md.

## TIME TO REASSESS TORNADO RATINGS

We need a new tornado intensity classification scale. We urge engineers, meteorologists, disaster relief workers, representatives of standards organizations, regulatory bodies and the insurance industry to work together on its development. An improved tornado intensity classification scale would include damage descriptions that make specific reference to basic design wind speeds and to construction quality as defined by conformity to standards.

As a basis for discussion, we suggest that wind speed ranges included in tornado intensity classifications be affected by numerical factors related to the basic design wind speeds and to construction quality.

Factors relating to quality of construction could be specified in accordance with matrices of the type considered by insurance companies, where conformity to various standards is estimated both qualitatively and quantitatively.

ASCE, in collaboration with other interested parties, should consider organizing and training volunteer engineering teams at the section level that could work with local NOAA and other specialized personnel and promptly record significant evidence on tornado intensities. Our experience shows that evidence of tornado effects is often removed from the site within a day of the tornado's occurrence, before survey teams can reach the site.

Next, documentation for the approximately 150 tornadoes (about 0.5% of the total number of recorded tornadoes in the U.S.) classified as F5 should be revisited to reassess the classification. This would involve a relatively small effort and would, even if only partly successful, make it possible to update the database from which probability distributions of tornado wind speeds are estimated. This recommendation follows a proposal by Kishor C. Mehta of Texas Tech University.

Continuing efforts to develop procedures for obtaining direct, scientific tornado wind speed measurements should be encouraged. Such measurements would add valuable data to the database, even though the effect of such addition to the more than 25,000 records currently available would be small; many years of data would have to be collected for that effect to be significant.

On the other hand, scientific measurements can help to assess estimates of tornado wind speeds based on observations of damage. This in turn would help to correct the existing database by allowing the use of Bayesian or other updating techniques.

*—LP, ES*

Our special section on structural engineering starts off with a call to action. In "Tornado Aftermath: Questioning the Tools," authors Long Phan and Emil Simiu of the National Institute of Standards and Technology report on the agency's investigation of a destructive tornado in Texas. Fatalities numbered 27 and property damage was similarly extensive, including 40 residences. The engineers suggest that the Fujita intensity scale needs to be reassessed. They argue that an improved scale—one that would include references to basic design wind speeds and to the quality of construction as defined by standards—could avert some of the devastation caused by tornadoes.

Building in congested urban areas poses lots of engineering challenges. In "Building between Buildings," structural engineer R. Shankar Nair describes methods to transfer loads and considers other strategies to deal with urban constraints in design and construction. His experiences are in Chicago, but his observations are applicable elsewhere.

Our third article, "Shake, Rattle and Hold," by Chris Pantelides, Evert Lawton, Lawrence Reaveley and Scott Merry, deals with seismic durability tests on a bridge in Salt Lake City that provided engineers with reams of performance data on an old concrete-reinforced bridge section. After conducting the initial lateral displacement tests, the researchers repaired the bridge with fiber-reinforced plastic composites to test promising rehabilitation techniques. The on-site testing should help engineers design better bridges and rehabilitation techniques for earthquake-prone areas.

As always, feedback is welcome.

VIRGINIA FAIRWEATHER
*Editor-in-Chief*