Lessons Learned from the Damage Produced by the Tornadoes of 3 May 1999

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ABSTRACT

After the tornadoes of 3 May 1999, the Federal Emergency Management Agency formed a Building Performance Assessment Team (BPAT) to examine the main tornado paths during the outbreak and to make recommendations based on the damage they saw. This is the first time a tornado disaster has been subjected to a BPAT investigation. Some aspects of the BPAT final report are reviewed and considered in the context of tornado preparedness in Kansas and Oklahoma. Although the preparedness efforts of many public and private institutions apparently played a large role in reducing casualties from the storm, a number of building deficiencies were found during the BPAT's evaluation. Especially in public facilities, there are several aspects of tornado preparedness that could be improved. Moreover, there is clear evidence that a nonnegligible fraction of the damage associated with these storms could have been mitigated with some relatively simple and inexpensive construction enhancements. Widespread implementation of these enhancements would reduce projectile loading and its associated threats to both life and property.

1. Introduction

As events unfolded in Oklahoma and Kansas on 3 May 1999, it became clear that this day was going to test severely the tornado preparedness of communities in these two states. The largest outbreak of tornadoes ever to hit the state of Oklahoma left scores of paths of destruction, including an F5 tornado with a 61-km (38 mi)-long path that crossed several interstate highways and devastated several suburban areas of Oklahoma City. In the days following the event, various groups conducted numerous surveys in an attempt to assess the damage to residential, public, and commercial buildings and to evaluate the performance of the tornado preparedness efforts. This included the first-ever survey of a tornado event by a Building Performance Assessment Team (BPAT), created by the Federal Emergency Management Agency (FEMA). The intensity and extent of the damage was high enough to warrant the creation of FEMA's first-ever tornado BPAT; as noted in the final report (BPAT 1999),

> The number of tornadoes that occurred on May 3, 1999, in Oklahoma and Kansas, their severity, and the level of devastation they caused have not been seen in a generation within the United States.

BPATs have been used by FEMA to review how well structures have performed in various disasters (hurricanes, earthquakes, etc.), with the goal being to reduce the damage created by similar events in the future. Because this was the first BPAT study ever devoted to a tornadic event, it necessarily is the benchmark study for improving building performance in tornado situations. The team created to review building performance in the paths of the 3 May 1999 tornadoes was charged specifically to evaluate the performance of

1) private residences, including both single-family and multifamily structures;
2) public and commercial buildings, including schools, hospitals, factories, and so on; and
3) any tornado shelters in the path.

In this paper, we are not going to review the detailed findings and recommendations of the BPAT; those are provided in the final report of the team (BPAT 1999), and interested readers are advised to consult that report for a comprehensive treatment of the findings. Rather, herein, we wish to consider how the findings of that report relate to the overall process of tornado preparedness that has been evolving in the tornado-prone parts of the United States. Although that process includes the meteorological tasks of forecasting and warning for tornadoes, we are not going to review them here, because they are discussed elsewhere (Andra et al. 2002; Edwards et al. 2002). On this fateful day, it appears that

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preparedness in Oklahoma and Kansas paid off in terms of lives spared, but it was found that improvements in construction practice could reduce the amount of structural damage, which might offer additional reductions in casualties.

The notion of an integrated warning system (IWS) has been discussed in Doswell et al. (1999), wherein it was suggested that, "The IWS process actually can be said to begin well before any severe weather has even begun to loom on the horizon." That is, tornado preparedness involves considerable planning and effort in the months and years preceding an eventful day such as 3 May 1999. Since tornado and severe thunderstorm forecasting began in the United States, weather forecasters have assumed considerable responsibility for creating public awareness concerning severe weather hazards. For example, the spotter program requires training of local storm spotters, usually by the nearest office of the National Weather Service (NWS). The BPAT's investigation can be viewed in this context as providing information about how the structural integrity of buildings is part of the preparedness process. This issue is often overlooked by meteorologists.

Section 2 of this paper provides a few, selected highlights from the BPAT final report; the goal is not to be comprehensive but, rather, to note specific issues that will be examined herein. Section 3 presents the findings of an informal survey conducted during the BPAT on the character of home remnants left in the wake of the F5 tornado in the suburbs of Oklahoma City. In section 4, the findings from the BPAT survey are discussed in the context of the tornado preparedness program, and section 5 presents conclusions we draw from the study of the tornado damage.

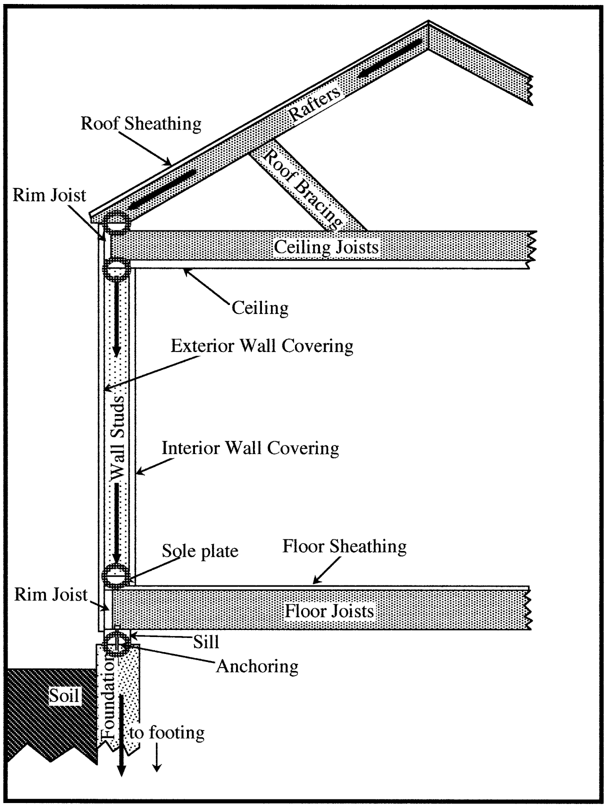

FIG. 1. Schematic illustration of the elements of the load path (bold arrows) for a single-story frame home; stippled circles indicate locations of critical attachments along the load path that are vital to the structural integrity of the home under various types of wind loading. The arrows show the "dead-load" path; under uplift forces created in a tornado, the arrows are reversed.

2. Selected findings from the BPAT report

a. Load path integrity

In engineering terminology, the so-called load path is the set of structures designed to carry the weight of a building. For buildings, this is typically the framing. Under normal conditions, the weight of the building is carried from the roof along the framing to the foundation and, ultimately, to the ground (Fig. 1). In Oklahoma, most of the residences do not have basements. Rather, most are on concrete slabs; a few are built on "crawl space" foundations. On the other hand, most homes in Kansas were on foundations that included basements, with some having crawl space foundations. This regional difference in construction practice is apparently associated with differences in soil types and problems with the water table in Oklahoma.

The issue of the continuity and integrity of attachments along the load path of a home was clearly a major factor in the damage viewed by the BPAT (BPAT 1999; Marshall 2002). This has also been the case in BPAT studies of hurricane disasters (BPAT 1993). In most cases, these attachments might marginally meet the building codes, but they provide little in the way of resistance to forces creating uplift. In some cases, the attachments did *not* meet building codes. In either case, when structures were subjected to tornadic winds, they would fail first at the weak points along the load path. Once failure was initiated at a weak point on the load path, considerable structural breakdown could follow. When a structural failure occurs, it also can begin with a breach of the external "envelope" of that building. This breach allows wind to enter and exert additional force on the walls and ceilings of breached rooms, leading to additional failures such as wall collapse and loss of roofs. Side loads from the winds could literally slide a home off its slab or foundation, resulting in additional structural failures and causing total destruction of the home.

In most cases of damage to homes, either in Oklahoma or Kansas, the attachments along the load path were inadequate to resist side loads and uplift generated by the wind. In general, the building codes currently in effect should prevent structural damage in winds up to about 90 mi h^{-2} (i.e., corresponding roughly

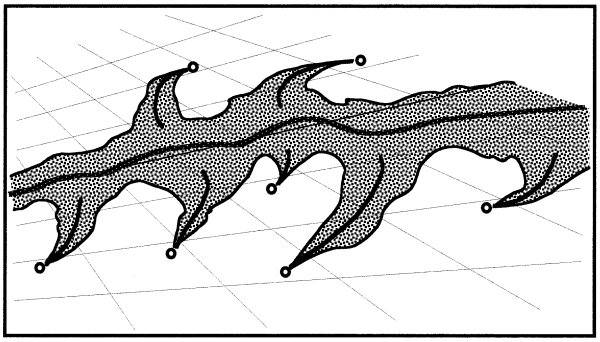

FIG. 2. Schematic illustration of how cones of damage might begin with weakly constructed structures (open circles), widening as they approach the centerline of the tornado's path (heavy line); thin straight lines represent city blocks and coarse stippling defines the area of structural damage within the tornado path.

to F1 wind speeds). Beyond that, increasing winds should result in increasing amounts of structural damage. For cases in which the codes are not met, of course, much weaker winds could initiate structural failures. Rural areas do not typically have building codes in force. Hence, construction practices in rural areas can vary widely, complicating any interpretation of the damage produced in an event. This was particularly evident in the rural segments of the tornadoes on 3 May 1999.

b. Projectiles

Once structural failures occur, the tornadic wind field becomes filled with debris, acting as projectiles (or, ''missiles'') that fly at high speed. When tornadoes interact with homes, common projectiles are broken framing timbers and pieces of masonry. These projectiles can breach the external envelope of other homes and thereby can initiate failures that might not otherwise have occurred. The BPAT found numerous instances in which major structural failures occurred on the far periphery of a tornado path, typically attributable to building code violations or marginal construction practices. These failures would generate projectiles of various sizes, perhaps up to the size of whole roofs, that would hit other buildings and initiate further structural failures. In effect, off to the side of the tornado's centerline, there would be ''cones of damage'' that would widen as they approached the path center, illustrated schematically in Fig. 2. Each of these damage cones would begin at some notably weak structure, surrounded on three sides by other structures suffering little or no structural damage. One weak structure, therefore, could create additional structural damage in nearby structures that would otherwise have suffered little or no damage. Because it is not possible after the fact to know just what would have happened in the absence of the initial failure, some caution should be used in applying this explanation of the damage cones too literally, of course. These damage patterns might also be a reflection of small-scale fluctuations in the wind speeds.

Within those parts of a tornado path that experience F2 and greater wind speeds, some structural damage is nearly inevitable. As noted, however, projectiles of all kinds create the potential for structural damage *outside* of the part of the path with F2 and greater wind speeds. Besides the breach-of-envelope process already mentioned, projectile impacts can cause failures in important structural elements that might otherwise have been able to resist the wind.

The BPAT observed that some very large projectiles are created in violent tornadoes. When a large, heavy projectile, such as an automobile or utility pole, strikes a structure, severe damage is likely to be the result. When a violent tornado strikes a populated area, the projectile load carried in the debris cloud of the tornado represents a substantially increased hazard in comparison with an equivalent tornado in an open, rural setting. In addition to increasing tornado damage potential, it is well known that being hit by a projectile is arguably the most important of the three major causes of casualties in tornadoes; the other two are becoming airborne and being crushed within collapsing structures.

On the periphery of the tornadoes on this day, considerable damage to brick veneer was found, typically owing to inadequate attachment of the masonry exterior walls to the framing of the home. Many of these failed attachments represented code violations of various kinds. The failure of masonry veneer generates a large source of projectiles (e.g., bricks) that can cause breach-of-envelope failures emanating from the failed masonry wall.

c. Garages

Many of the structures involved in the tornadoes were typical suburban single-family residences, and most of them had attached garages. Common garage door construction is relatively flimsy, so many of the garage doors failed. Most failed with inward (positive) wind pressure, and some with outward (negative) wind pressure. The cases with positive wind pressure constituted a breach of the envelope, permitting winds to enter the garage and create additional side loads and uplift. It was found that many garages were built with framing and attachments that were below code requirements, even when the residence met those code requirements. Apparently, this practice arises because garages are not considered to be living space, although code requirements do not make this distinction. The failure of the garage structure, when it was attached to the rest of the home, often initiated structural failures in the rest of the home. The orientation of the garage to the damaging wind was an important factor in the occurrence of damage; doors facing into the wind were more likely to be associated with structural damage to the residence than doors facing away from the wind.

d. Manufactured homes

In virtually all examples considered by the BPAT, it was evident that manufactured homes generally were far more vulnerable to tornadic damage than the typical site-built frame home. At one point, on the periphery of a violent tornado, a manufactured home that was anchored to the ground became airborne and was totally destroyed when it landed about 100 m away from its original site, whereas a nearby site-built home that was actually closer to the center of the tornado path experienced no more than F2 damage. Thus, even when the manufactured homes were anchored to the ground, the anchor straps often were either broken or pulled out of the ground. Anchoring methods for the manufactured homes and their integrity varied considerably from place to place during the survey.

e. Tornado preparedness

It was a surprise that, in many *public* facilities (some of the schools, many of the workplace buildings, etc.) there was only minimal preparation for dealing with tornadoes. Most of the facilities had little or no idea where the safest portions of the structure might be. In some examples, safe areas had been designated that did not appear to be consistent with the actual structural integrity of those areas. Most public facilities did not have a National Oceanic and Atmospheric Administration (NOAA) weather radio for monitoring the tornado threat and had only a rudimentary plan in place for tornado safety. At least one school used what amounted to manufactured homes on their campus for additional classroom space, and, in the event of a warning, the students in those buildings would have to evacuate their classroom and travel along walkways outdoors into the main building to seek shelter. That school did not have a NOAA weather radio on site. Moreover, the hallway in the main building designated as a shelter area did not appear to be structurally safe, owing to the presence of ‘‘clerestory’’ windows,[1] which are vulnerable to projectile penetration and reduce the resistance of the corridor walls to lateral wind forces.

A few facilities, like one manufacturing plant in Kansas, had done considerable planning for tornadoes. They used NOAA weather radios, had well-conceived plans for getting occupants to adequate shelters, and actually practiced executing their plans during drills 2 times per year. The plant in Kansas was damaged by the tornado, but the execution of their tornado action plan prevented any casualties. Of interest was that the person responsible for safety in the plant called for movement to shelter as if it were a drill, apparently to reduce the potential for panic.

Most of the public seems to have been using the information that the NWS and other organizations have been disseminating on what to do in the event of a tornado. Given the excellent NWS performance in this event (Andra et al. 2002; Edwards et al. 2002) and the widespread media attention prior to the arrival of most tornadoes, it seems obvious that the death toll was much less than what might have been expected. Given that many thousands of structures were heavily damaged or destroyed, a community that was less prepared might have suffered many more casualties [as discussed in Doswell et al. (1999)]. Note that although the violent tornado that struck in the Oklahoma City area was the first tornado ever to produce $1 billion in assessed damage, this figure may be misleading, owing to a steady increase of wealth in the United States (Pielke and Landsea 1998; Brooks and Doswell 2001).

f. Shelters

Despite being within what might reasonably be called ‘‘Tornado Alley,’’ there were relatively few tornado shelters found within the paths of the tornadoes in Oklahoma and Kansas. A number of below-ground shelters were found; many of them had a number of problems (notably, poor ventilation and water infiltration), but the biggest issue with most of them was the door and its attachments. Many of the doors were little more than plywood sheathed in metal, and some had deteriorated since their installation. Most troublesome were the absence of solid attachments, with flimsy hinges and a simple sliding bolt to hold the door. The general recommendation for shelter doors is six attachment points, including three sturdy hinges and three deadbolts, with all six attachments spaced roughly equally along the door sides.[2] Such a solid attachment of a door was not found during the BPAT survey. A relatively new in-ground shelter design performed well for its owner in an F4 damage area associated with the tornado near Wichita, Kansas, despite having some minor deficiencies in ventilation and door attachment. Although the BPAT found some deficiencies with the underground shelters, nevertheless they proved adequate to prevent serious injuries to their occupants. In one case, a backyard underground shelter door had been torn off its entrance and a clothes dryer had entered the shelter. As it turned out, in this case, the owners of that shelter had sought refuge in their *neighbor’s* underground shelter in preference to their own and so escaped injury. It is not known why they chose to use their neighbor’s shelter rather than theirs.

A handful of ‘‘safe rooms’’[3] constructed to meet

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[1] That is, windows designed for lighting at the top of the corridor walls.

[2] See ‘‘National Performance Criteria for Tornado Shelters,’’ pamphlet issued by FEMA, in collaboration with the Wind Engineering Research Center at Texas Tech University in Lubbock, Texas.

[3] The FEMA recommendations for these safe rooms, developed in collaboration with engineers from Texas Tech University, are summarized in ‘‘Taking Shelter from the Storm: Building a Safe Room Inside Your House,’’ a free pamphlet issued by FEMA.

FEMA recommendations had been constructed in and near tornado paths. Apart from some questions regarding door attachments, these safe rooms performed as intended; no casualties occurred in them. One such safe room was on the outskirts of F4 damage in Midwest City, Oklahoma. Another was on the periphery of F5 damage near Bridge Creek, Oklahoma.

One manufactured-home park in Kansas had a community shelter. Numerous problems were found with that shelter, including

- shelter access (door was normally locked),
- lack of access for persons with disabilities,
- long travel times for some of the residents to reach the shelter,
- rules for access that excluded personal pets,
- moisture infiltration,
- poor ventilation, and
- inadequate doors and hardware.

The shelter was partially underground, and the flat roof was covered with a loose stone aggregate that likely would become a source of small projectiles in strong winds. The rule excluding pets apparently resulted in the death of a man who was refused admittance after he chose not to abandon his dog.

3. Core remnants study

As an unofficial part of the study, one of us (CAD) participated in a nonsystematic examination of those homes that had lost roofs and exterior walls but still had some interior walls standing (and so would be rated as F3 damage). In effect, during the BPAT survey, we considered ‘‘targets of opportunity’’ as we walked along the damage path in residential housing areas. There was no attempt to find and assess *all* such remaining interior walls (hereinafter called core remnants). The goal was to determine the kind of rooms left standing in F3 damage areas. According to the Fujita scale (e.g., Fujita 1981), at damage levels of F4 and F5, no interior walls are left standing, so occupant survivability is a matter of luck if the occupants cannot reach adequate shelter.

After the pioneering engineering studies done by the engineers at Texas Tech University in the years since the Lubbock, Texas, tornado of 11 April 1970 (Fujita 1970), the NWS and other agencies charged with tornado safety have recommended that occupants of residences who cannot gain access to proper shelter (either below ground or within an in-house safe room) should seek shelter in interior rooms (without windows). The idea is to put as many walls between the occupants and the exterior as possible. Bathrooms, closets, and under stairways have been recommended, owing to the additional structural elements that might resist the tornadic winds. It seems that most residents within the path of the 3 May 1999 tornadoes followed these instructions. We were interested to confirm the validity of this advice.

Results of our informal study are shown in Table 1. During the first part of the work (data points 1–38), we only determined which kind of room was left among the core remnants. As our study proceeded, however, we found that several rooms could remain within the core at the same time, so data points 39–94 do not necessarily represent independent core remnants. The finding is clearly in favor of seeking shelter in bathrooms or closets, if adequate shelter is not available. Kitchens often were reduced to one standing wall that typically included cabinets, on the other side of the wall from a hallway leading to a bathroom or closet. Whereas the bathrooms or closets usually provided what clearly would have been adequate shelter in most such cases, the kitchens on the other side of the remaining interior wall were regularly found to be open to the outside on three sides and so would be very hazardous. Projectiles penetrated the walls of some otherwise relatively intact core-remnant rooms, rendering them unlikely places to avoid serious injury or death.[4]

TABLE 1. Results of informal core-remnants survey. Subjective determination was made concerning the likelihood of avoiding serious injury or death within the remnant rooms, corresponding to the yes/no columns under each room type. A yes means a *high* likelihood of avoiding serious injury or death, whereas a no means a *low* likelihood of avoiding serious injury or death. The first 38 data points were all independent core remnants, and each core remnant was determined to be one of the set (kitchen, closet, or bathroom). Subsequent data points (38–91) are not necessarily independent core remnants, because it was determined that core remnants might include any or all of the set (kitchen, closet, or bathroom).

Data point	Kitchen		Closet		Bathroom	
	Yes	No	Yes	No	Yes	No
1–38	5	33	27	11	29	9
39–94	0	0	30	8	45	11
All	5	33	57	19	74	20

4. Discussion of findings

It is very clear from the outcome of this devastating outbreak of tornadoes that, on the whole, the public in Oklahoma and Kansas is reasonably well prepared to handle tornado disasters. The limited toll of fatalities, given the enormous magnitude of the event, is a tribute to the many long hours of effort, spread out over many years, by the public and private institutions responsible for public safety in this part of Tornado Alley. We believe it is unlikely that this performance would be possible in parts of the country in which the perceived hazard of tornadoes is much lower than in Oklahoma and Kansas.

However, the story regarding damage to structures from the storm is much less optimistic. It is hard to understand how and why construction practice is so

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[4] We had no way of knowing the actual outcome regarding injuries or fatalities to those occupying core-remnant rooms during the tornado.

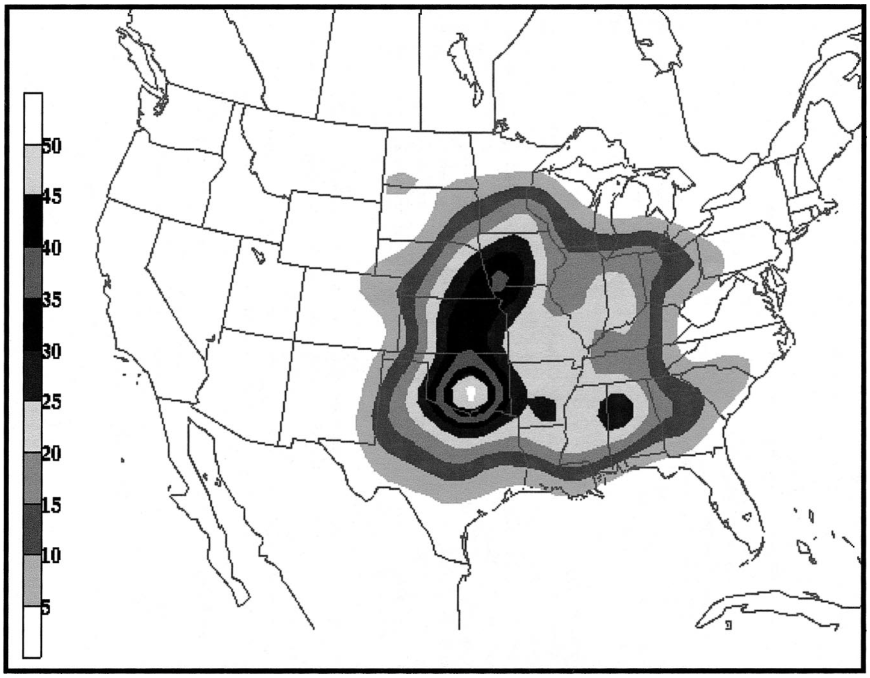

FIG. 3. Frequency of days per millennium with one or more violent (F4/F5) tornado touchdowns within a grid box of 80 km on a side, based on tornado data from 1921 to 1995. This figure can also be found online at http://www.nssl.noaa.gov/hazard.

marginal in that part of the nation with the highest likelihood of violent tornadoes (Fig. 3). It seems obvious that no affordable, practical home could survive intact from the impact of F4 or F5 tornadic wind speeds. However, several facts are relevant to this. First of all, violent (F4 and F5) tornadoes are unlikely events, even when given that a tornado has occurred. Violent tornadoes are only a few percent of the total number of tornadoes. Moreover, in a violent tornado, the strongest winds (i.e., those of F4 or F5 intensity) occupy only a small percentage of the damage path. From what the BPAT report shows, some relatively modest enhancements to the construction of a house (e.g., ‘‘hurricane clips’’ that tie together the framing members along the load path and anchor bolts attaching the bottom plate of a wall to the foundation or slab) could reduce the damage, and especially the *structural* damage, done to homes in the parts of a tornado path that experience winds of F3 or lower intensity. The installation costs for these enhancements are nominal for new construction, even including labor. Retrofitting these construction enhancements into existing construction is unfortunately not very practical and would be much more expensive.

Limiting the damage to residences is not so simple as having one’s own home built properly. As the BPAT findings make clear, having poorly constructed homes in the neighborhood increases *everyone’s* chances for serious damage from F2 or lower wind speeds, even if isolated individual homes are capable of resisting structural damage at those wind speeds. The best way to decrease the damage potential from surrounding structures is for *all* the structures to be enhanced over existing codes. That is, it would be necessary to make *entire communities* more resistant to tornadic winds to gain the full benefit from construction enhancements beyond existing codes.

It is clear, as well, that efforts must be undertaken to reduce the likelihood of serious injuries or fatalities associated with manufactured homes. It was curious that in the Oklahoma City–area tornadoes, no manufactured-home parks were hit. Only in the unincorporated community of Bridge Creek was there a concentration of manufactured homes hit by the tornado, resulting in 11 of the 36 fatalities produced by the F5 tornado. The likelihood of having another violent tornado sweep through a populated area without hitting manufactured home parks is probably not very high and appears to be decreasing (Brooks and Doswell 2002).

In some parts of the country, there are ‘‘parks’’ at which recreational vehicles of those on extended vacations stay for months at a time, representing another highly vulnerable residence. Local authorities often do not know how many people are in such temporary ‘‘housing’’ areas, because the residents are highly transient. In locations dominated by the presence of manufactured homes or recreational vehicles, the inherent vulnerability of such residences suggests that construction enhancements are unlikely to do much to reduce the potential casualties. Therefore, the way to protect the residents (even if they are only temporary) must be to provide adequate shelters. There are many possible options for this that might be practical.

It is also difficult to understand how and why the public in Oklahoma and Kansas generally has lost interest in building tornado shelters, either below ground or as in-home safe rooms. With FEMA's financial assistance, some fraction of the rebuilt homes in the paths of the 3 May 1999 storms will now include an in-home safe room. The challenge clearly is to convince the public that it is worth an investment of several thousand dollars to construct some form of tornado shelter, even though most people have not yet experienced a tornado hit firsthand, and, given that the event's return frequency is on the order of 1000 years for any particular square mile in central Oklahoma, it is unlikely they *ever* will experience a tornado.

Although the 3 May 1999 tornadoes were devastating, they are by no means indicative of the worst possible events. In addition to not hitting very many manufactured-home parks, the tornadoes did not hit any public facilities with a large vulnerable population. Such events have happened in the past, but apparently many public facilities (including workplaces) are not very well prepared to handle tornado disasters. The United States has not had a large school in session hit by a significant tornado since the 1950s.[5] The BPAT findings of a considerable shortfall in tornado preparedness by some schools and other public facilities represent a considerable challenge to those institutions that have accepted responsibility for public safety.

5. Conclusions

The events of 3 May 1999 contain several lessons regarding tornado preparedness. The first is that, at least within the plains region of the United States where tornadoes are most common, the level of preparedness is sufficient to result in a substantial reduction in casualties. Most people were aware of what to do in the event of a tornado, and the actions they took resulted in a remarkably low death toll for this event, given the intensity and number of tornadoes. The forecast and warning system in place is working well, especially for major events. The concept of the integrated warning system, which includes a collaboration between public- and private-sector institutions, provided excellent warnings and information to the public. Although we have not discussed it, the emergency response after the event appears to have been excellent and no doubt was responsible for amelioration of considerable postevent suffering.

However, another important lesson is that the preparedness program still has some aspects that need improvement. This fact is particularly noticeable in the area of public facilities, including workplaces. Even within central Oklahoma, the nation's center for severe-weather awareness, many schools, sporting facilities, workplaces, shopping areas, and other public facilities do not have adequate tornado-preparedness plans. The current minimal use of the NOAA weather radio as a means for getting NWS warnings as soon as possible, especially for public-use facilities (schools, factories, sporting events, etc.) is a disturbing finding, and we conclude that this sorely needs to be addressed. Many public facilities need to work with someone trained to recognize the presence (or absence) of truly safe shelter areas within their structures. If no safe shelter exists within the existing buildings, then shelters clearly need to be constructed. Practical plans for getting occupants to shelter in the event of a tornado need to be developed in many places, and need to be practiced at least 2 times per year.

It seems inexplicable that the public has increasingly chosen not to build tornado shelters in the tornado-prone areas of the United States. The choice to build a shelter is clearly a personal one, given that it requires a considerable investment, and should remain optional rather than mandatory for private residences. In tornado-prone areas, home builders should be encouraged to offer safe rooms as an option in new construction, whereby it is possible to amortize the cost of a safe room over the length of a mortgage. However, we conclude that serious consideration should be given to mandating the construction of shelters for mobile-home and recreational-vehicle parks and in many other public facilities (especially in schools and day-care centers).

Recently, the North Texas Council of Governments has used the data from the 3 May 1999 event to simulate what might happen if a similar outbreak of tornadoes hit in north Texas.[6] The results of this study are staggering, including the potential for several billion dollars in damage and thousands of casualties. The outcomes of these experiments depend strongly on the specific circumstances of the outbreak: time of day, day of the week, the details of just what lies in the path, and so on. Such hypothetical scenarios represent what we consider to be a sobering dose of reality. As noted in Doswell et al. (1998), public apathy as a result of the long interval between major disasters continues to be a major factor in reducing tornado preparedness. Despite seeming to represent a form of ''scare tactics,'' the development of such scenarios around the tornado-prone parts of the United States is certainly to be encouraged, if for no other reason than to offset public apathy.

Damage mitigation has been given only minimal at-

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[5] On 16 November 1989, a number of schoolchildren were killed by a falling wall in Newburgh, New York, by what was called a tornado (rated F1). It is virtually certain that this was *not* a tornado, but was a downburst.

[6] ''Tornado Damage Risk Assessment,'' unpublished report available from North Central Texas Council of Governments, 616 Six Flags Dr., Suite 200, Centerpoint Two, P.O. Box 5888, Arlington, TX 76005-5888. More information is available online at http://www.dfwinfo.com/weather/study.html.

tention over the years. Reducing damage is arguably of lower priority than reduction of casualties, and it is apparent that many believe there is nothing that can be done to resist violent tornadoes. However, it is also apparent that reduction of damage could well be a factor in reducing hazards to the public. That is, for example, if we can minimize the projectile load in tornadoes by eliminating unnecessary structural damage outside of F4 and F5 wind speed areas (only a tiny fraction of the total area affected by tornadoes), then it is likely that this would result in reduced casualties. Home builders in tornado-prone areas should be encouraged to offer enhanced load path attachments as an option, preferably within whole developments, to reduce damage created by debris from weakly constructed nearby homes. Perhaps the insurance industry can be encouraged to offer premium reductions for homeowners who live in disaster-resistant developments (including safe rooms). We are very supportive of FEMA's Project Impact,[7] which seeks to develop communities that are resistant to a wide range of disasters, including tornadoes.

As our understanding of tornadoes has grown, it has become increasingly clear that damage mitigation from tornadoes is quite possible. As with other aspects of tornado preparedness, a process of damage mitigation necessarily begins long *before* a potential tornado day. If there is to be some positive impact on how decisions are made regarding damage mitigation and shelter construction, a considerable effort must be expended by those public and private institutions responsible for public welfare in disasters. It is hoped that we can develop a collaboration among all those institutions rather than a disorganized collection of individual programs.

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[7] Information about Project Impact can be found online at: http://www.fema.gov/.