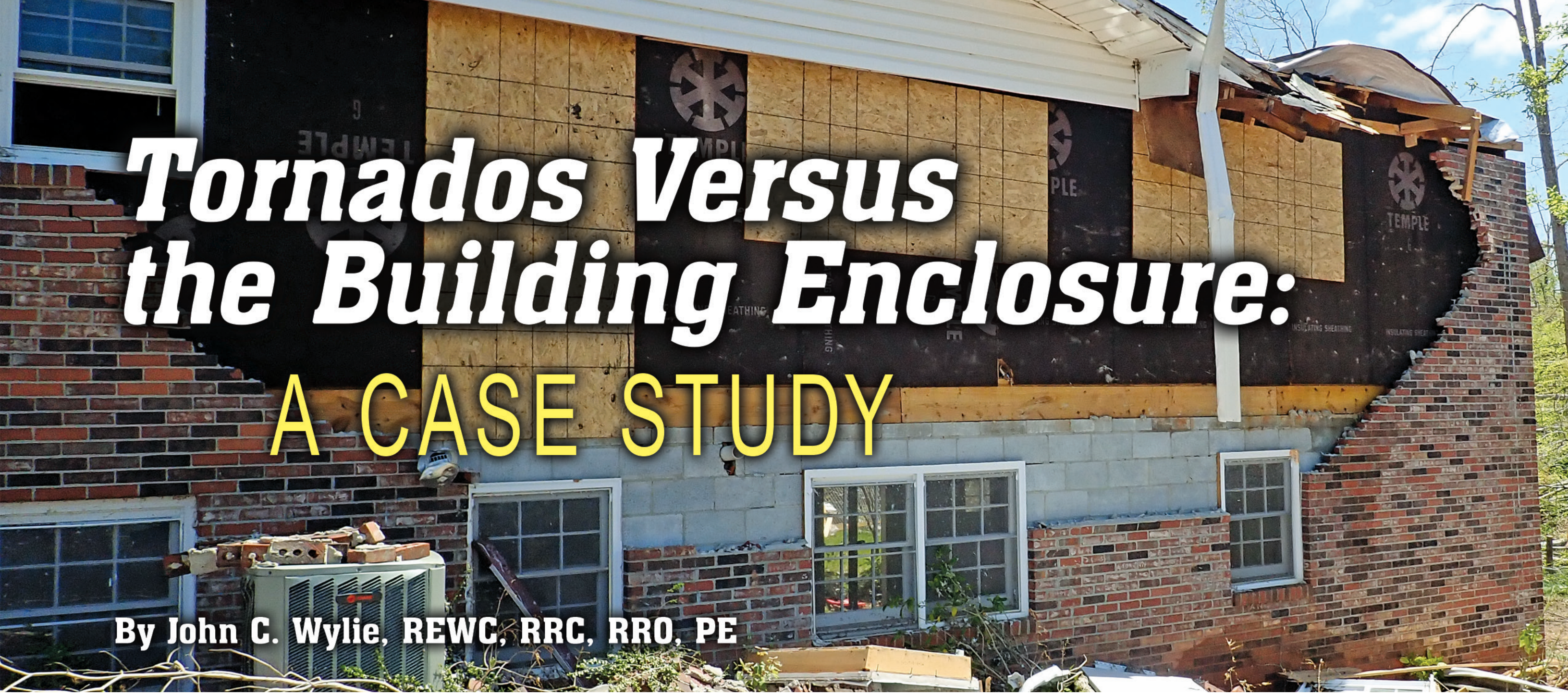

Tornados Versus the Building Enclosure: A CASE STUDY

By John C. Wylie, REWC, RRC, RRO, PE

The intent of any building code is to provide the minimum legal requirements related to (a) constructing a building at a reasonable level of safety and (b) providing protection to the general public and property. As design professionals, we are tasked with ensuring that the structural frame can resist against earthquakes, fires, and extreme weather, and the building enclosure itself can prevent incidental and unwanted moisture from penetrating the interior. However, building codes do not account for every extreme event that could affect a building. For example, extreme weather events, such as tornadoes, can generate wind pressures that exceed the wind pressures specified in the local building code.

The focus of this case study is to demonstrate the variety of tornado-related damages relative to the building enclosure. Based on the author's firsthand account of a tornado event, this case study will display the degree of damage to the building enclosure for four residential structures adjacent to the tornado path that traversed more than 16 miles (26 km) through several communities in upstate South Carolina.

BACKGROUND

Meteorologists such as those working for the National Oceanic and Atmospheric Administration in the National Weather Service (NWS), National Severe Storms Laboratory, Storm Prediction Center, and National Centers for Environmental Information recognize general factors affecting tornado formation, but they are still researching the exact causes. They have determined that tornadoes develop in supercell thunderstorms that contain persistent wind updrafts from the convergence of warm air and cool air. Within the supercell thunderstorm, the wind updrafts can reach speeds of 100 mph (160 km/hr), and strong vertical wind shears cause a rotating cylinder of air that is lifted vertically by the updrafts. As the rotating cylinder is lifted vertically, it stretches and begins to spin faster, creating a low pressure at the surface forming a tornado funnel.[1]

To classify a tornado's rate of intensity, the NWS uses the Enhanced Fujita (EF) Scale,[2] which evaluates the tornado's estimated wind speeds and the related degree of observed damage to structures and vegetation. **Table 1** provides the basic parameters of wind gusts and degree of damage used in the EF Scale.

EF rating	Estimated wind gust (mph)	Damage scale
EF0	65–85	Minor
EF1	86–110	Moderate
EF2	111–135	Considerable
EF3	136–165	Severe
EF4	166–200	Devastating
EF5	>200	Incredible

Note: 1 mph = 1.6 km/hr.

Table 1. Enhanced Fujita (EF) Scale parameters. Source: National Oceanic and Atmospheric Administration. "Storm Prediction Center." Accessed August 2, 2021. https://www.spc.noaa.gov

CASE STUDY

On April 13, 2020, the NWS confirmed that an EF3 tornado had passed through several communities in upstate South Carolina (**Fig. 1**).[3] The NWS office for Greenville-Spartanburg, South Carolina, stated that a large and significant tornado crossed through three counties with estimated wind speeds of 160 mph (260 km/hr). The ½-mile-wide (0.8 km) tornado traveled approximately 16½ miles (27

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PUBLIC INFORMATION STATEMENT
NATIONAL WEATHER SERVICE GREENVILLE-SPARTANBURG SC
522 PM EDT MON APR 13 2020

...NWS DAMAGE SURVEY FOR EF3 TORNADO EVENT...

START LOCATION...3 SSE WESTMINSTER IN OCONEE COUNTY SC
END LOCATION...2 W CENTRAL IN PICKENS COUNTY SC
DATE...04/13/2020
ESTIMATED TIME...03:20 AM EDT
MAXIMUM EF-SCALE RATING...EF3
ESTIMATED MAXIMUM WIND SPEED...160 MPH
MAXIMUM PATH WIDTH...900.0 YARDS
PATH LENGTH...16.66 MILES
BEGINNING LAT/LON...34.6175 / -83.0834
ENDING LAT/LON...34.7329 / -82.8263
* FATALITIES...1
* INJURIES...?

...SUMMARY...
A  LARGE AND SIGNIFICANT TORNADO PASSED THROUGH PARTS OF OCONEE
AND PICKENS COUNTIES EARLY MONDAY MORNING, BEGINNING SOUTH OF
WESTMINSTER, AND ENDING NORTH OF CLEMSON.  MAXIMUM STRUCTURAL
DAMAGE TO HOUSES AND A LARGE WAREHOUSE IN THE AREA INDICATE PEAK
WINDS NEAR 160 MPH, FOR A STRONG EF3 RATING. DAMAGE EXISTS OVER A
WIDE SWATH, AND THE WIDTH OF THE TORNADO WAS AT LEAST A HALF MILE.
THERE IS ONE KNOWN FATALITY, NUMEROUS INJURIES, AND 2 PEOPLE STILL
MISSING AT THE TIME OF THIS STATEMENT.

EF SCALE: THE ENHANCED FUJITA SCALE CLASSIFIES TORNADOES INTO THE
FOLLOWING CATEGORIES:

EF0...WEAK......65 TO 85 MPH
EF1...WEAK......86 TO 110 MPH
EF2...STRONG....111 TO 135 MPH
EF3...STRONG....136 TO 165 MPH
EF4...VIOLENT...166 TO 200 MPH
EF5...VIOLENT...>200 MPH

* THE INFORMATION IN THIS STATEMENT IS PRELIMINARY AND SUBJECT TO
CHANGE PENDING FINAL REVIEW OF THE EVENT AND PUBLICATION IN NWS
STORM DATA.

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Figure 1. National Weather Service statement about the April 13, 2020, tornado in upstate South Carolina.

km) in a northeast direction and caused extensive structural damage to structures (**Fig. 2**).

Following the tornado event, the author was contracted by the catastrophe claims branch of an insurance company to assess the tornado-related damage at four residential properties (two townhouses and two single-family houses) located between 100 ft to 4000 ft (30 m to 1200 m) from the approximate centerline path of the EF3 tornado (**Fig. 3**). **Table 2** briefly summarizes the residential property information for the assessed structures. The residential structure identification numbers (R-1 through R-4) indicate the sequence in which the four buildings were impacted by the tornado event.

Figure 2. Approximate path and length of the EF3 tornado.

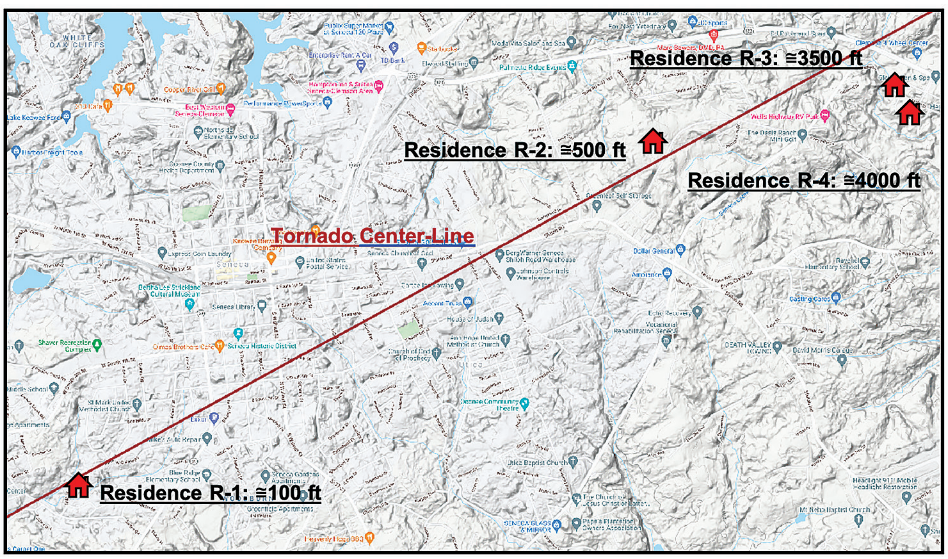

Figure 3. Approximate location and distance of residential properties relative to the tornado centerline.

Damage Assessment

In visual assessments, varying degrees of tornado-related damage to the building enclosures were observed at the four residential properties. This damage included, but was not limited to, the following:

- Complete displacement of the wood roof framing, wood roof decking, and roof covering (**Fig. 4**)
- Localized displacement of laminated composition shingles (**Fig. 5**)
- Unadhered laminated composition shingles (**Fig. 6**)
- Displaced metal rake trim (**Fig. 7**)
- Partial displacement of brick veneer cladding (**Fig. 8**)
- Partial displacement of vinyl siding (**Fig. 9**)
- Complete displacement of window unit from the rough opening (**Fig. 10**)
- Out-of-plane displacement of aluminum garage door framing and panels (**Fig. 11**)

An unmanned aerial vehicle (drone) was employed to survey and assess the residential structures and the adjacent landscape and vegetation for tornado-related damage. The damage path was observed to be widest at residence R-1 (**Fig. 12**) and narrower as the tornado progressed toward residence R-4 (**Fig. 13** and **14**). Though the degree of damage was observed to decrease as the tornado progressed in the northeast direction, the type and direction of damage to the trees and other vegetation was observed to be consistent.

Wind Pressure Analysis

A preliminary wind pressure analysis was performed in general accordance with ASCE 7-16, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*,[4] to demonstrate the relative difference between

Residential structure identification	Type	Exterior cladding	Steep-slope roof configuration	Roof covering	Year of construction
R-1	Single family	Brick veneer	Simple gable	Laminated composition shingles	1968
R-2	Single family	Brick veneer	Offset gable	Laminated composition shingles	1987
R-3	Townhome	Vinyl siding	Simple gable	Laminated composition shingles	1982
R-4	Townhome	Vinyl siding	Offset and intersecting gable	Laminated composition shingles	1985

Table 2. Summary of residential property information.

Figure 4. View of displaced wood roof framing, roof decking, and roof covering.

Figure 5. View of displaced shingles at ridge.

the code-prescribed wind pressures and the wind pressures produced by the tornado event. **Table 3** provides a summary of the preliminary wind pressure analysis of a typical one-story single-family building located in upstate South Carolina. As the table shows, the ratio between the wind pressures produced by the tornado event and the wind pressure specified in ASCE 7 is greater than 2. This indicates that the building enclosure components were subjected to wind pressures that exceeded the design pressure specified in ASCE 7.

Figure 6. View of unadhered laminated composition shingle.

Figure 7. View of displaced metal rake trim.

Figure 8. Partial displacement of brick veneer cladding. OSB panels cover window and door openings.

Figure 9. View of displaced vinyl siding.

Discussion

From a structural standpoint, residential buildings with conventional wood construction are generally considered to be flexible and can absorb and dissipate vertical and lateral loads caused by wind pressures, seismic movements, or short-duration impact loads. Wood components have an increased resistance when subjected to short-duration loadings (for example, small impacts) versus long-duration loadings (for example, heavy isolated objects). When a structure is subjected to a vertical and lateral load, the wood framing members and wall sheathing act together (as shear walls and diaphragms) to resist the movements. The resistance to these movements is dependent on the combination of wood fram-

Figure 10. View of complete displacement of window from rough opening.

Figure 11. View of damaged aluminum garage door framing and panels.

Figure 12. Damage adjacent to residence R-1.

Figure 13. Damage adjacent to residence R-2.

ing connections, wall sheathing attachment, roof decking attachment, and anchorage to the foundation.

Regarding the building enclosure, its components (such as, roof coverings, exterior cladding, windows, garage doors) transfer the interacting loads directly to the structure skeleton and into the foundation. Design professionals and consultants use building codes and specifications to determine the maximum loadings to which these components will likely be subjected during their service life. However, if the forces applied to these components exceed the design maximum loadings, damage or failure of the components is probable.

As noted, the width and intensity of tornado damage to the

Figure 14. Damage adjacent to residences R-3 and R-4.

surrounding landscape and vegetation decreased from residence R-1 to residence R-4; however, the type of exterior cladding and the age of the roof covering also affected the degree of damage to the residences. For example, at residence R-1, the brick veneer was partially displaced due to the wind pressures developed during the tornado event. Furthermore, a localized section of the roof system was completely displaced, starting at the end of the roof eave, where wind pressures are considered to be the highest. As wind pressures penetrate an opening in the exterior wall or roof area, the interior behaves similar to an expanding balloon and adds supplemental outward pressure. This type of effect can exacerbate the displacement of the roof system or displacement of a fenestration.

At residence R-4, the vinyl siding was displaced, even though R-4 was subjected to lower wind pressures than residence R-1. The attachment of residence R-1 and residence R-4 exterior cladding systems are different—with brick veneer physically attached with corrugated brick ties and vinyl siding being hung on a wall—both exterior cladding systems experienced varying degrees of displacement.

Residence R-1 was subjected to the EF3 tornado at maximum wind speeds, and the other three residences were subjected to lower tornado wind speeds that also exceeded the code-prescribed wind speed. Building codes take into account a variety of presumed worst-case scenarios based on different types of loadings (such as, snow, wind, seismic) to formulate load cases. However, this case study illustrates that those scenarios do not cover all conditions. Extreme weather events that produce wind speeds that far exceed a code-prescribed wind speed, such as an EF3 tornado or greater, can make the structural and architectural designs to resist the EF3 cost prohibitive to construct.

CONCLUSION

Though building codes and standards provide the minimum legal requirements related to constructing a building at a reasonable level of safety, they do not account for every extreme event that could occur. In this case study, the wind pressures generated by an EF3 tornado exceeded the code-prescribed wind-pressure resistance. Several factors, including the relative location of the residential structure to the centerline of the tornado and type of exterior cladding, affected the extent of damage to the building enclosure components. Design professionals and consultants should be mindful of the interaction of the building enclosure and the potential for damage from extreme weather events.

Wind zone	Location	ASCE 7-16 wind pressure specification (lb/ft^2)	Tornado wind pressure (lb/ft^2)	Ratio of tornado wind pressure to ASCE 7-16 specified wind pressure
Zone 1	Roof	–33	–73	2.21
Zone 2e		–33	–73	2.21
Zone 2n		–47	–106	2.26
Zone 2r		–47	–106	2.26
Zone 3e		–47	–106	2.26
Zone 3r		–56	–126	2.25
Zone 4	Wall	–19	–43	2.26
Zone 5		–24	–53	2.21

*Assumptions: Exposure category = exposure B; enclosure category = enclosed building; roof configuration: simple gable.

Note: 1 lb/ft^2 = 0.048 kPa.

Table 3. Summary of preliminary wind pressure analysis.*

REFERENCES

1. National Oceanic and Atmospheric Administration. "The Online Tornado FAQ." Accessed August 2, 2021. https://www.spc.noaa.gov/faq/tornado/
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John C. Wylie, REWC, RRO, PE

John C. Wylie has over 12 years of experience as an engineering consultant—primarily in the areas of deficient construction, structural analysis, and collapse/damage investigations. He is responsible for the inspection and repair of a wide variety of building enclosure systems and structural systems. Wylie is licensed as a professional engineer in four states and is a Registered Roof Consultant, Registered Exterior Wall Consultant, and Registered Roof Observer with IIBEC.