22 May 2019 JEFFERSON CITY, MO TORNADO: FIELD ASSESSMENT STRUCTURAL TEAM 1 (FAST-1) EARLY ACCESS RECONNAISSANCE REPORT (EARR)

(Top) Damaged Hawthorne Park Apartment Complex (Source: UAV video from FAST-1). (Bottom) Members of FAST-1 from the Missouri University of Science and Technology and the Wind Hazard Assessment and Mitigation Team (WHAM).

FAST-1 Members

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David B. Roueche, Auburn University

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Executive Summary

At around 11:40 PM on Wednesday, May 22, 2019 an EF-3 tornado struck Jefferson City, the capital of the state of Missouri, causing extensive structural damage. The tornado formed near Eldon, MO and traveled from southwest to northeast for 19.5 miles before dissipating just east-northeast of Jefferson City, MO. The heaviest damage was experienced along the 5 mile portion of the path through Jefferson City, MO and achieving an estimated peak wind speed of 160 mph, based on National Weather Service (NWS). Coincidentally, eight years ago, on the same day, an EF-5 tornado struck Joplin, MO, just 200 miles southwest of Jefferson City. The damage to the downtown portion of a capital city warranted more detailed structural investigation through a StEER Field Assessment Structural Team (FAST), which was led by the Wind Hazard Mitigation (WHAM) laboratory of Missouri University of Science and Technology (Missouri S&T). Deployments were conducted between May 23 and May 28 to collect the perishable data utilizing door-to-door assessments, Lidar scanning and drones. This Early Access Reconnaissance Report (EARR) provides an overview of Jefferson City Tornado, MO of 22 May 2019, StEER's event response, and preliminary findings based on FAST-1's collected data.

In general, FAST-1 observed that the tornado completely destroyed or severely damaged numerous homes and business as it passed through the city. For example, some apartment buildings in Hawthorne Park Apartment complex were destroyed; a number of historical buildings downtown were severely damaged; a long reinforced masonry wall of the old State Penitentiary (1 foot thick) was knocked down; a number of power poles for transmission lines fell to the ground, as shown in the figures at the very end of this file. Along the tornado path, a variety of trees were snapped and uprooted. Fortunately, no fatalities were reported. It has been ranked as EF-3 by NWS.

All observations and findings provided in this report should be considered preliminary and are based on the limited scope of FAST-1. FAST-1's primary focus was structural damage to buildings in and around the tornado's path. The majority of the structures assessed by the FAST-1 were considered historic, with the average year built being 1933, and the newest building constructed in 1990. Specific recommendations of areas worthy of further investigation by the community are offered at the conclusion of this report. Specific recommendations of areas worthy of further investigation are offered at the conclusion of this report.

Introduction

At around 11:40 PM on Wednesday, May 22, an EF-3 tornado tore through Jefferson City, from Southwest to Northeast with a path of 5 miles (the entire path is 19.38 miles), based on National Weather Service (NWS). Eleven structures were destroyed and one hundred fifty seven were damaged in the event[1]. In addition to this damage, several historical locations around the Jefferson City area that had survived previous storms and weather cycles had been damaged, including a one-foot thick masonry wall at the old State Penitentiary, which was over 100 years old. Fortunately, no fatalities were reported during this event, which is in stark contrast to the tornado that passed through Joplin, MO on this same date in 2011, which claimed the lives of 161 people (Huang et al, 2016)[2].

The StEER Field Assessment Structural Team (FAST), comprised of members of the Wind Hazard Mitigation Laboratory (WHAM) at the Missouri University of Science and Technology, was mobilized to collect valuable information immediately after the disaster occurred. Data collection was performed using Door-to-Door Assessments (using the Fulcrum app, provided by StEER), Lidar scanning, and overhead drones. Although this tragedy resulted in the loss of homes and businesses in the Jefferson City community, the data that was collected has the potential to impact future designs and research, which can possibly minimize the property loss in future tornadoes.

The first product of the StEER response to the Jefferson City, MO Tornado is this **Early Access Reconnaissance Report (EARR)**, which is intended to:

1. provide an overview of the tornado
2. overview StEER's event strategy in response to this tornado
3. summarize the activities, methodologies and preliminary findings of the first Field Assessment Team (FAST-1)

Data collected and processed in this deployment will be published in DesignSafe following completion of the Data Enrichment and Quality Control procedures.

> It should be emphasized that all results herein are preliminary and based on the rapid assessment of data within 24 hours of its collection. As such, the records have not yet been processed by the StEER Quality Assurance protocol. Damage ratings discussed herein are based largely on the judgement of the surveyor on the ground without access to additional aerial imagery and will be updated when the full dataset is released on DesignSafe under Project ID PRJ-2113. The raw data is now available for viewing in the Fulcrum Community page: https://web.fulcrumapp.com/communities/nsf-rapid

[1] Fleck, M. (2019). More than 150 buildings damaged in Jefferson City tornado. Abc17news. <https://www.abc17news.com/news/more-than-150-buildings-damaged-in-jefferson-city-tornado/1080622889>. Accessed June 6, 2019.

[2] Huang, Z., Fan, X., Cai, L., & Shi, S. Q. (2016). Tornado hazard for structural engineering. *Natural Hazards*, 83, 1821-1842.

Meteorological Background

Storm cells developed over the Mid-Mississippi River Valley from May 21 to 23. During this activity, specifically on May 22, a warm front moved north, which increased low-level moisture. Combining this with a cold front that came in from the west, sufficient wind was developed in the area that made tornadoes more likely [3]. At 10:56 PM CDT, a tornado touched down and traveled through Cole County picking up strength, increasing from an EF-1 to an EF-2, before finally developing into an EF-3 just prior to reaching Jefferson City, MO. The tornado had an estimated peak wind speed of 160 miles per hour with a maximum width of 1500 feet. At any given point however, the maximum wind speed and direction from which it occurs is a function of the distance to the tornado center, the local terrain surrounding the point, and the presence of any convective features within the tornadic wind field. It was estimated to have traveled a total of 19.38 miles, causing significant damage along its path. In total, storms generated five tornadoes in the county warning area over three days, including the EF-3 tornado that struck Jefferson, City.

StEER Response Strategy

FAST-1 WHAM team collected data from May 23 to May 28 along the tornado path within Jefferson City (about five miles) using the following technologies: Door-to-Door assessments, Lidar Scanning and Unmanned Aircraft Systems (UAS).

Detailed forensic investigations were generally not achievable within the scope and time limits of FAST-1. Instead, FAST-1 focused on broadly assessing building performance over large expanse of the impacted area and over a wide range of structural typologies. If recommended, future StEER deployments or RAPID-style grants can focus on specific typologies or regions. Specific, hypothesis-driven research is generally outside of the scope of StEER, although data collected by StEER can be used for these purposes in some cases.

Local Codes & Construction Practices

The State of Missouri has not adopted a statewide building code. Code adoption and updating is left to each county and local municipality. In Jefferson City, MO, the current enforced building codes are the 2015 International Building Code (IBC) and the 2015 International Residential Code (IRC), both of which were adopted in 2017 [4]. Prior to adoption of the 2015 IBC/IRC, the 2009 edition of the same codes were in effect.

Reconnaissance Methodology

FAST-1 used its **Targeted D2D Assessment Team** to conduct door-to-door (D2D) damage assessments at predefined clusters spanning from an apartment complex on the southwest side

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[3] National Weather Service, St. Louis, MO, “May 21-23, 2019 Severe Thunderstorms”.
[4] <http://www.jeffersoncitymo.gov/government/building_regulations/building_codes.php>. Accessed June 6, 2019.

of the city to historical buildings on the northeast side. UAS was deployed in tandem whenever possible (based on FAA restriction) to provide high resolution aerial imagery to capture roof condition, debris paths, and condition of surrounding structures.

D2D Assessments

D2D Damage Assessments enable a detailed construction classification and evaluation of condition/component damage levels. These were recorded using a Fulcrum mobile smartphone application acquiring geotagged photos and other relevant metadata from the surveyor's mobile device. The App development was informed by the experience of the 2017 Hurricane Season and reorganized into a Fulcrum project, allowing FAST members to select assessment forms customized for buildings, non-buildings, or hazard indicators.

FAST emphasis is placed on documenting the performance of as many buildings as possible in a short amount of time, while still capturing the minimal depth of information needed for a useful assessment. This information includes 1) collecting clear photographs from multiple perspectives, 2) accurately geo-locating the assessments, 3) filling out site-specific fields which require on-site forensic investigation, 4) noting unique features of structures that would affect windstorm performance and not be otherwise visible from UAS data. To avoid biasing, D2D damage assessments were conducted on every third house within the pre-identified cluster and every house in areas that underwent extreme damage, specifically areas where several destroyed buildings were seen in close proximity.

Following the field deployments, members of the FAST executed an abbreviated Data Enrichment and Quality Control protocol to verify the location of each assessment, standardize the overall wind damage ratings assigned, and build out the basic attributes of each building including number of stories, roof shape, building use, and year built.

Unmanned Aerial Surveys

Unmanned Air Surveillance (UAS) was conducted at Hawthorne Park Apartment complex. The UAV hardware that was utilized was a Go Pro Karma drone, which performed overflights of Jefferson City, primarily used for video recording. Specifically at the Hawthorne Apartments, the altitude was maintained at 80 feet.

Fig. 1 Drone photos of the Hawthorne Park Apartment Complex.

Lidar Scanning Surveys

Lidar scanning was performed using a Leica ScanStation P40. This particular device has a maximum range of 270 meters with a 360° horizontal and 270° vertical field of view. The accuracy is ±1.2 mm, with an additional 1 mm for every additional 100 m. The device precision is to 0.1 mm. Depending upon precision and sensitivity of interest each scan may take between 20 seconds and 215 minutes. Control and data transfer can be achieved with Wi-Fi. In all the device weighs under 12.5 kg (28lb) and can be set up in less than 5 minutes. Figure 2 presents the overview of the Hawthorne Park Apartment Complex and a building on the tornado track obtained from Lidar Scanning. Fifteen separate locations, shown in Figure 3, were scanned and combined into the 3D images shown in Figure 2.

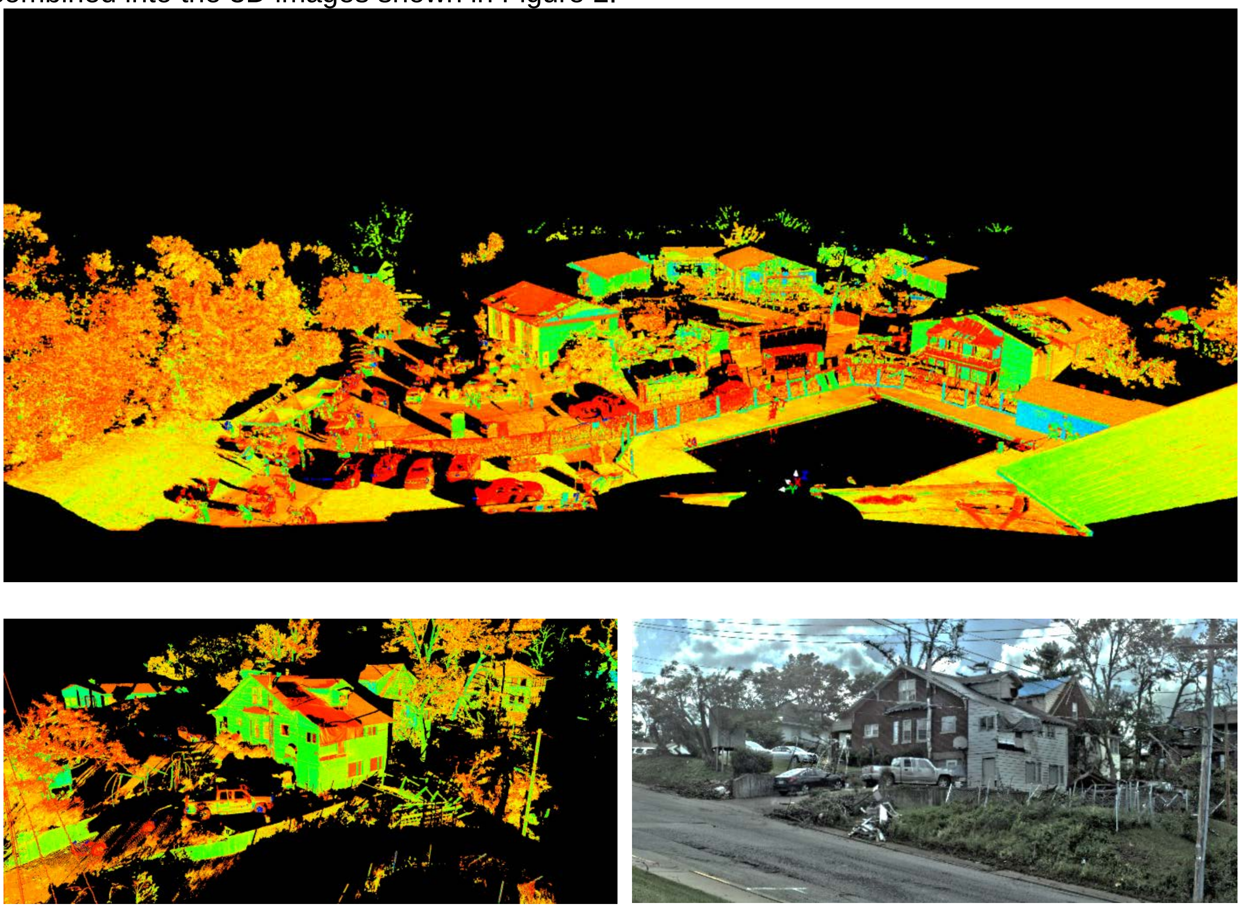

Fig. 2 Lidar scanning of the Hawthorne Park Apartment Complex and a damaged house on tornado path

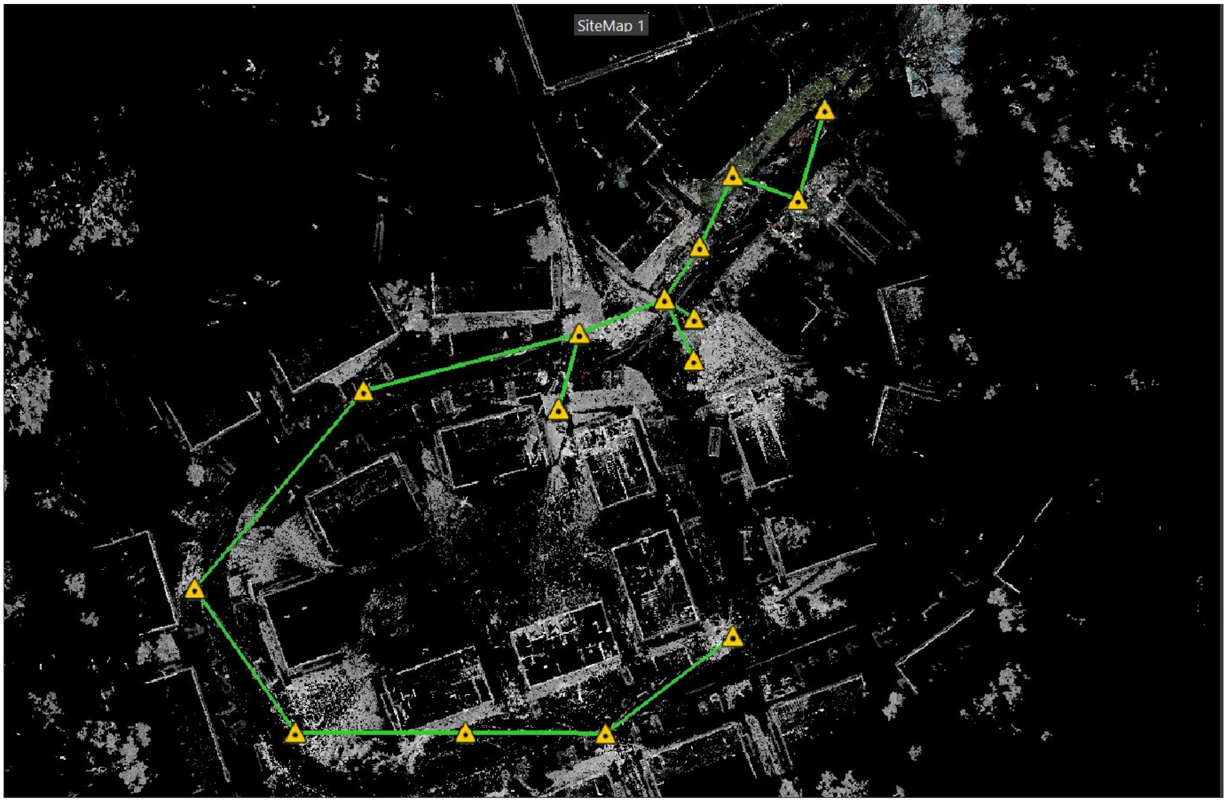

Fig. 3: Lidar scanning locations in Hawthorne Apartment complex.

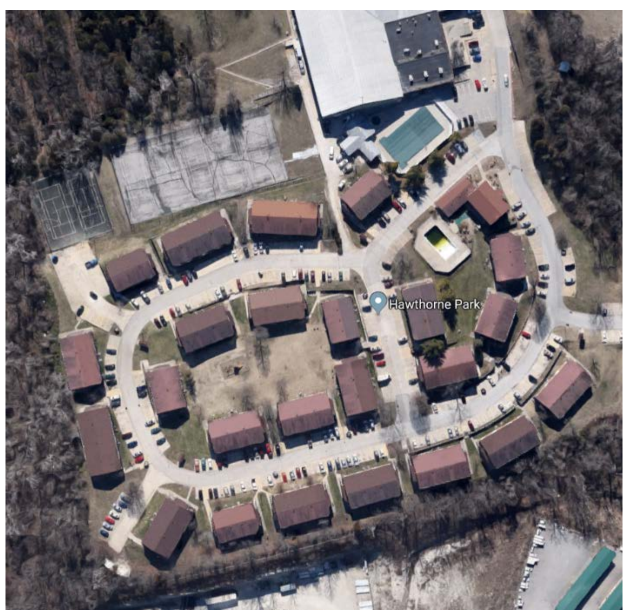

Fig. 4: Pre-tornado view of the Hawthorne Apartment complex (Source: Google Maps)

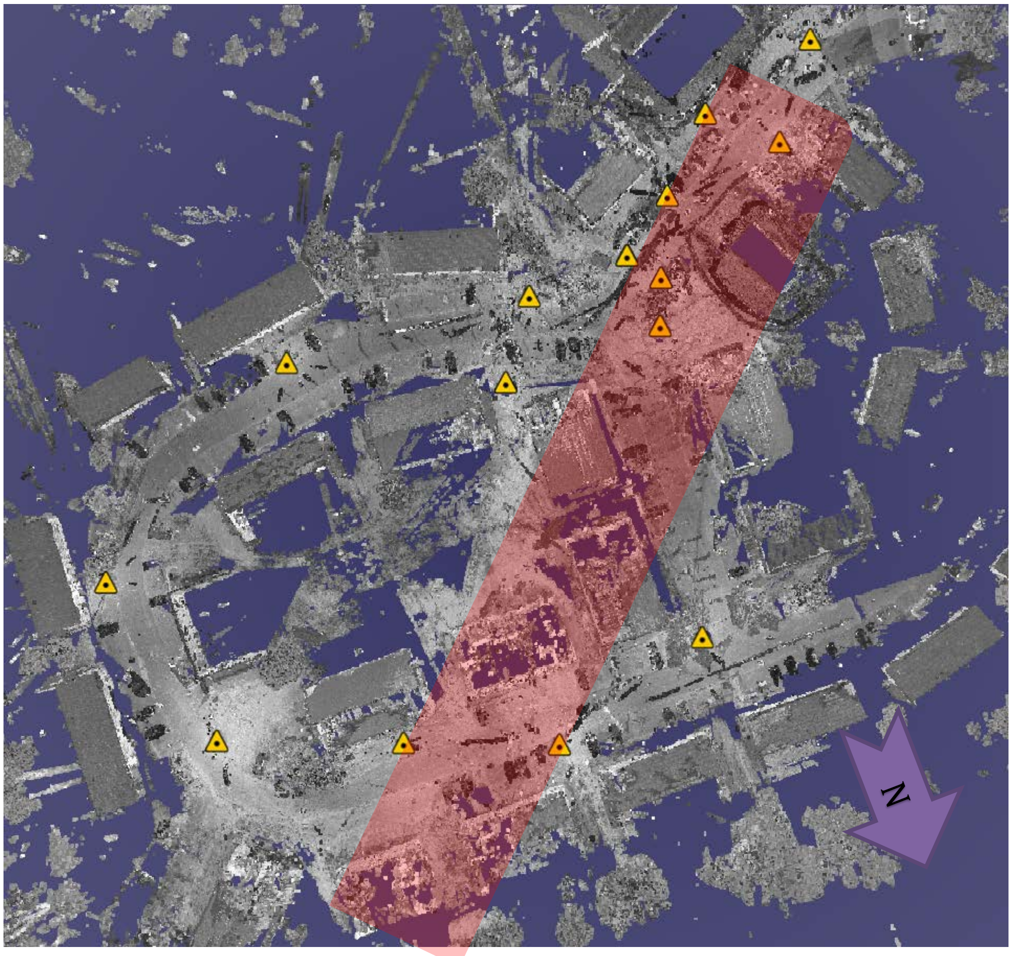

Fig. 5: Drone image of Lidar scanning locations in Hawthorne Apartment complex with suggested tornado path in red tint.

Observations

Observations of damage and conditions in the regions assessed by FAST-1 are now summarized. The majority of the structures assessed by the FAST-1 were considered historic, with the average year built being 1933, and the newest building constructed in 1990. The tornado completely destroyed or severely damaged numerous homes and businesses as it passed through the city. For example, some apartment buildings in Hawthorne Park Apartment complex were destroyed (they are all brick veneer buildings); a number of historical buildings downtown were severely damaged; a long reinforced masonry wall of the old State Penitentiary (1 foot thick) was knocked down; a number of posts for transmission lines fell to the ground, as shown in the figures at the very end of this file. Fortunately, no fatalities were reported. It has been ranked as EF-3 by NWS. The assessment data presented was collected between May 24th and May 25th, 2019.

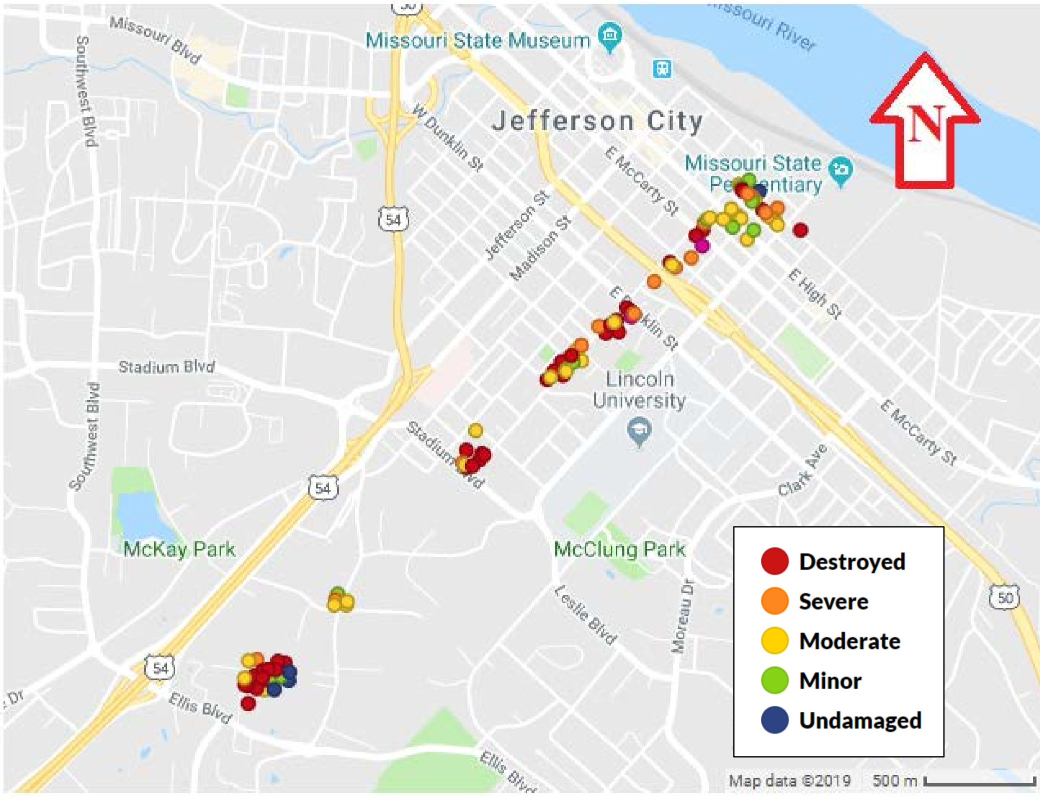

Fig. 6: Map of Jefferson City Door-to-Door assessment locations.

Single-Family Residential Buildings

Sixty five single-family residential buildings were surveyed in the D2D assessment; those sustaining damage had preliminary overall wind damage ranging from moderate to destroyed depending upon the proximity to the tornado path. Although it is of note that several homes that were in the tornado path avoided damage. Preliminary analysis of D2D data in the sampled clusters indicates damage predominantly driven by wind and windborne debris and largely windows and roofs were damaged. The building in Figure 7 appears to be a slab on grade building with two stories. The exterior is brick, whether it is veneer or not is hard to determine. The upper story has damage to the roof over the upstairs windows, which suggests a failure of the separate roof over the gable window roof system and not the main truss system.

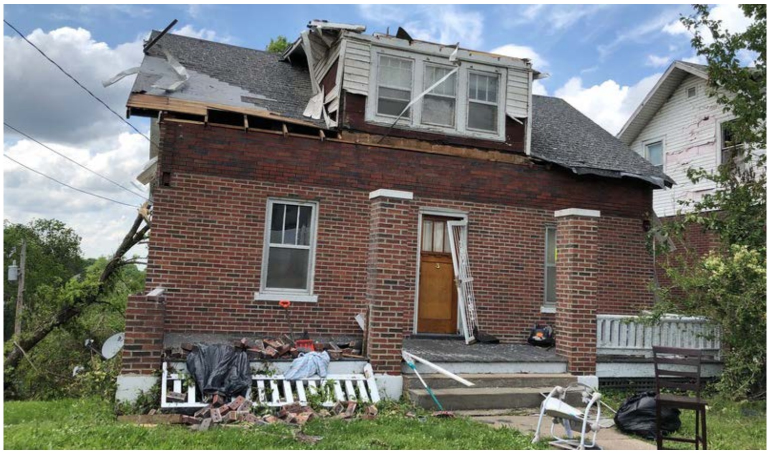

Fig. 7: Typical single-family residence with damage to windows and the roof.

Multi-Family Residential Buildings

Twenty apartment buildings were surveyed in the D2D assessment; those sustaining damage had preliminary overall wind damage ratings of severe to destruction. Preliminary analysis of D2D data in the sampled clusters indicates damage predominantly driven by wind and windborne debris and largely the brick veneer and roof/truss/wall systems were destroyed or damaged. Figure 8 is a multi-family residential building that has complete destruction of the upper nearest apartment. The exterior is brick veneer. The veneer failed on this structure in the un-collapsed wall of the lower apartment. The building is slab on grade.

Fig. 8: Multi-family residence with total destruction of the second floor apartment.

Commercial/Historical Buildings

Eight commercial buildings and historical buildings used as offices were surveyed in the D2D assessment; those sustaining damage had preliminary overall wind damage ratings of moderate to destroyed. Preliminary analysis of D2D data in the sampled clusters indicates damage predominantly driven by wind and windborne debris and largely roof damage is present. Figure 9 shows a historical building with a column supported second story balcony. The balcony appears to be intact, however the entire roof has collapsed into the second story of the building.

Fig. 9: Historical building that was used as an office. Total roof collapse visible from street.

Professional/Government Buildings

Two professional/government buildings were surveyed in the D2D assessment; those sustaining damage had preliminary overall wind damage ratings of severe to destroyed. Preliminary analysis of D2D data in the sampled clusters indicates damage predominantly driven by wind and largely wall and window damage was present. Figure 10 shows an exterior wall for the old State Penitentiary that has blown over. The wall is one foot thick, and appears to be constructed of heavy stone and mortar.

Fig. 10: State Penitentiary wall was blown over by wind.

Accessibility: As of June 6th, 2019, severe flooding in Jefferson City has resulted in closure of several roads near the Missouri river, but major highways are clear at this time.
Site Conditions: As of June 6th, 2019, power and services are available throughout the city except in severely damaged or destroyed areas.

Recommendations for Further Study

FAST-1 primarily focused assessments on Jefferson City locations along the tornadoes immediate path. Preliminary review of assessments logged by the team in these areas, in addition to observations by the team members as they traveled throughout the impacted areas, have led to the following recommendations for future study.

1. Historical building resilience. Although the historical homes and other buildings have survived many severe storms, they did not survive the tornadic winds. The loss of historic buildings can have increased impact on the community well-being and culture. This leads to the question of whether building practices for historical structures can be retrofitted to add strengthening components, such as imbedded supports, etc.
2. Retrofits to prevent roof failure. Cost-effective retrofit strategies are needed to provide stronger connections between roof and walls in existing buildings.
3. Brick veneer failure. Design and installation of metal ties between the brick veneer and wall substrate needs improvement.

Appendix: Photos of typical damage to residential and commercial buildings

Fig. A1 Entire roof was blown away; wall collapsed; brick veneer fell off.

Fig. A2 Partial roof was blown away; wall collapsed; brick veneer fell off.

Fig. A3 Partial roof was blown away; wall fell off.

Fig. A4 Partial roof truss was severely; wall collapsed.

Fig. A5 Entire roof was severely damage; glass door is destoryed.

Fig. A6 Partial roof was blown off; brick veneer fell off.

Fig. A7 Side wall collapsed.

Fig. A8 Side wall collapsed.

Fig. A9 Entire roof was blown away.

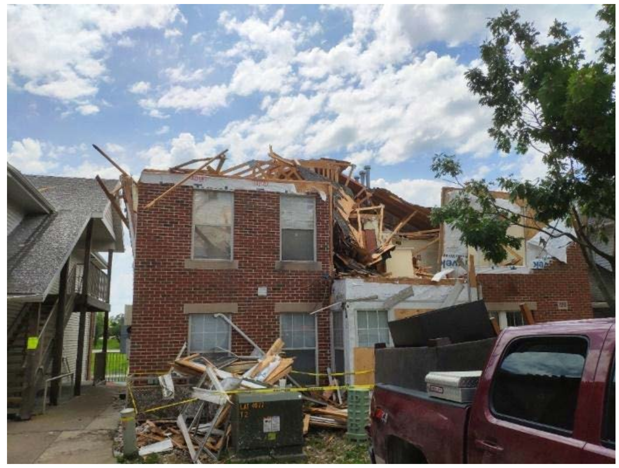

Fig. A10 Entire roof was severely damaged; wall fell off.

Fig. A11 Partial roof was blown away; brick veneer fell off.

Fig. A12 Partial roof was blown away; wall collapsed; brick veneer fell off.

Fig. A13 Steel roof was severely damaged.

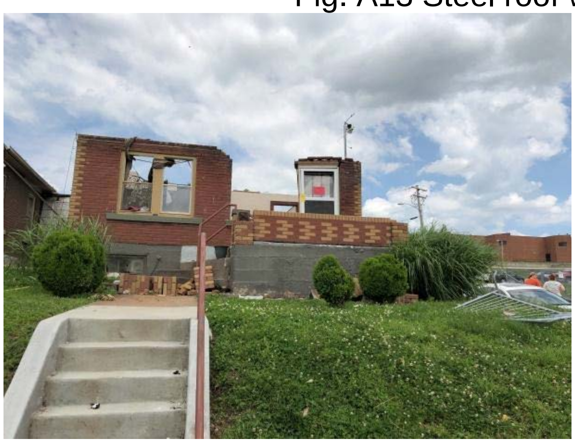

Fig. A14 Entire roof was blown away; wall collapsed; brick veneer fell off.

Fig. A15 Partial roof was blown away; wall collapsed; brick veneer fell off.


Fig. 16 Entire roof was blown away; wall collapsed; brick veneer fell off.


Fig. 17 Partial roof was blown away; wall collapsed; brick veneer fell off.


Fig. 18 Entire roof was blown away; wall collapsed; brick veneer fell off; glass was broken.

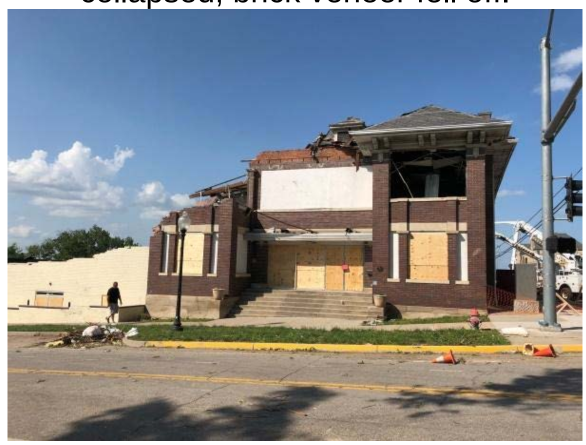
Fig. 19 Partial roof was blown away; wall collapsed; glass was broken.

Acknowledgements

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StEER further thanks the Coordination Support Team members (many who worked anonymously) to gather information on access and conditions on the ground for FAST-1, as well as a number of students at StEER nodes who assisted with FAST-1's preparations:

- Andrew Careaga, Department of Marketing and Communications
- Chris Finley, Community Manager of Hawthorne Park Apartments, Haley Residential
- Brad Eckel, Construction Project Manager, Haley Residential

About StEER

The National Science Foundation (NSF) awarded a 2-year EAGER grant (CMMI 1841667) to a consortium of universities to form the Structural Extreme Events Reconnaissance (StEER) Network. StEER's mission is to deepen the structural natural hazards engineering (NHE) community's capacity for reliable post-event reconnaissance by: (1) promoting community-driven standards, best practices, and training for RAPID field work; (2) coordinating official event responses in collaboration with other stakeholders and reconnaissance groups; and (3) representing structural engineering within the wider extreme events reconnaissance (EER) consortium in geotechnical engineering (GEER) and social sciences (SSEER) to foster greater potentials for truly interdisciplinary reconnaissance. StEER also works closely with the NSF-supported Natural Hazards Engineering Research Infrastructure (NHERI) RAPID facility and cyberinfrastructure Reconnaissance Portal to more effectively leverage these resources to benefit StEER missions.

StEER relies upon the engagement of the broad NHE community, including creating institutional linkages with dedicated liaisons to existing post-event communities and partnerships with other key stakeholders. While the network currently consists of the three primary nodes located at the University of Notre Dame (Coordinating Node), University of Florida (Atlantic/Gulf Regional Node), and University of California, Berkeley (Pacific Regional Node), StEER aspires to build a network of regional nodes worldwide to enable swift and high quality responses to major disasters globally.

StEER's founding organizational structure includes a governance layer comprised of core leadership with Associate Directors for each of the primary hazards as well as cross-cutting areas of Assessment Technologies and Data Standards, led by the following individuals:

- **Tracy Kijewski-Correa (PI),** University of Notre Dame, serves as StEER Director responsible with overseeing the design and operationalization of the network.
- **Khalid Mosalam (co-PI),** University of California, Berkeley, serves as StEER Associate Director for Seismic Hazards, leading StEER's Pacific Regional node and serving as primary liaison to the Earthquake Engineering community.
- **David O. Prevatt (co-PI),** University of Florida, serves as StEER Associate Director for Wind Hazards, leading StEER's Atlantic/Gulf Regional node and serving as primary liaison to the Wind Engineering community.

- **Ian Robertson (co-PI),** University of Hawai'i at Manoa, serves as StEER Associate Director for Assessment Technologies, guiding StEER's development of a robust approach to damage assessment across the hazards.
- **David Roueche (co-PI),** Auburn University, serves as StEER Associate Director for Data Standards, ensuring StEER processes deliver reliable and standardized reconnaissance data.

StEER's response to Hurricane Michael preceded the formation of its official policies, protocols and membership, which are still in active development. All policies, procedures and protocols described in this report should be considered preliminary and will be refined with community input as part of StEER's operationalization in 2018-2019.

StEER Event Report Library

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