StEER: Structural Engineering Extreme Event Reconnaissance Network

HURRICANE FLORENCE: FIELD ASSESSMENT TEAM 1 (FAT-1) EARLY ACCESS RECONNAISSANCE REPORT (EARR)

(UAV selfie courtesy of Blake Lytle)

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Executive Summary

Hurricane Florence made landfall as a Category 1 hurricane at Wrightsville Beach North Carolina, about five miles east of Wilmington, at 7:15 AM EDT 14 September 2018. While wind gusts topped out at only 105 mph, the storm's impressive size and slow forward speed resulted in significant flood-induced impacts. The Structural Engineering Extreme Events Reconnaissance (StEER) Network mobilized to assess the damage in the impacted region, deploying its first Field Assessment Team (FAT-1) to conduct door to door damage assessments and unmanned aerial surveys September 20-22, 2018. This Early Access Reconnaissance Report (EARR) provides an overview of Hurricane Florence, StEER's event response, and preliminary findings based on FAT-1's collected data.

In general, FAT-1 observed wind, storm surge, wave and erosion damage that was much less than previous major hurricanes impacting the area (Fran in 1996 and Floyd in 1999), not unexpected based on its intensity at landfall and improved construction practices over the last 20 years. Flooding due to inundation and rainfall remain the major drivers of losses in this event.

- **Structural Wind Damage:** In the coastal communities between Bogue Banks and New Hanover County, relatively little structural wind damage was observed, though some noteworthy failures were documented at Figure Eight Island. Non-building structures (signage, gas station canopies) and tree damage was observed widely, even outside of the highest simulated windfield contours, through Emerald Isle and into Atlantic Beach.
- **Building Envelope Performance:** Minor to severe roof cover loss was widespread and have been tarped in most of the surveyed area (making additional on-site assessments difficult). Asphalt shingles and vinyl siding (especially when installed over existing wood panel siding) has the highest observed incidence of damage.
- **Water Penetration:** In many cases when building envelopes appeared intact, significant water penetration still occurred resulting in extensive damage to the interior structure and contents. This is just the latest instance of this recurring issue in major hurricanes.
- **Storm Surge Damage:** Storm surge impacts were most significant on Topsail Island, particularly at the north end, in part due to the coastal protective features used in that region. Overall, the elevated construction practices in the surveyed coastal areas resulted in very little to no structural damage due to storm surge/flooding.

While FAT-1's assessed only the barrier islands in the impacted area, damage was also sustained along the estuaries and further inland as a result of storm surge as well as strong winds possibly associated with convective storms throughout the area to the right of the eyewall. Specific recommendations of areas worthy of further investigation are offered at the conclusion of this report.

Introduction

Hurricane Florence made landfall as a Category 1 at Wrightsville Beach, North Carolina, about five miles east of Wilmington, at 7:15 AM EDT September 14, 2018, moving in a westerly direction at 6 mph. The development of the Hurricane Florence is particularly noteworthy as it progressively weakened (from its peak Category 4 strength on September 11, 2018) during its final approach to the Carolinas. While wind gusts topped out at only 105 mph, the storm's impressive size and slow forward speed resulted in significant flood-induced impacts. As the storm lingered along the coast for multiple tidal cycles and remained over the area for several days, the combined storm surge and heavy rainfall generated significant flood-induced impacts over North and South Carolina. Mandatory evacuations were issued for all municipalities in counties along the barrier islands of North Carolina and remained in effect until approximately one week after the storm made landfall.

StEER's response to Florence had a two-fold objective. The first being the swift capture of perishable data through a coordinated strategy to improve our understanding of the performance of coastal construction under this event. The second viewed this response as an opportunity to prototype the protocols, procedures, policies and workflows that StEER will be developing over the next two years in collaboration with the Natural Hazards Engineering research community, the Natural Hazards Engineering Research Infrastructure (NHERI) and other members of the Extreme Events Reconnaissance Consortium.

The first product of the StEER response to Hurricane Florence is this **Early Access Reconnaissance Report (EARR)**, which is intended to:

1. provide an overview of Hurricane Florence, particularly as it relates to the wind, storm surge and inland flooding impacts in coastal North Carolina
2. overview StEER's event strategy in response to Hurricane Florence
3. summarize the activities, methodologies and preliminary findings of the first Field Assessment Team (FAT-1)

> 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-2092. The raw data is now available for viewing in the Fulcrum Community page: https://web.fulcrumapp.com/communities/nsf-rapid

Meteorological Background

Figure 1 shows the development of Hurricane Florence in its approach toward the southeastern United States. Concerns over Florence grew considerably as the storm strengthened to Category 4 intensity on September 11, 2018. Even as the storm weakened, dropping roughly a category a day up until its landfall as a Category 1 on September 14, the storm's size remained impressive. Florence's hurricane-force winds extended 80 miles from the eye, tropical-storm-force winds extended 195 miles outward with cloud cover over 400 miles in diameter (Fig. 2).

As illustrated by Figure 3, wind gusts along the North Carolina coast varied from 60 to 105 mph during the storm's landfall, with a narrow contour of 100 mph winds north and east of Wilmington. The ASOS station at Wilmington Airport recorded a peak 90 mph sustained wind speed (equivalent to 105 mph 3-second gust) during Hurricane Florence. This constituted the highest gust wind speed recorded at Wilmington International Airport since Hurricane Donna in 1960. The highest wind speeds observed during Florence were generally recorded on the right side of the hurricane track, coming out of the northeast. At any given point however, the maximum wind speed and direction from which it occurs is a function of the distance to the hurricane eyewall, the local terrain surrounding the point, and the presence of any convective features within the hurricane wind field.

Preliminary analysis of storm surge inundation caused by Hurricane Florence, including deployed instruments and storm surge simulation models such as ADCIRC (Fig. 4), indicates the maximum storm surge was approximately 9 ft above mean sea level (MSL). Maximum storm surge inundation above ground level was generally less than 5 ft, even on the barrier islands. Florence broke multiple tide records in the state of North Carolina, e.g., Wrightsville Beach experienced tides 4.11 feet above high tide on September 14, breaking a record set by Hurricane Joaquin in 2015 by more than a foot.

Southern North Carolina received significant rainfall as a result of Florence (Fig. 5), with estimated totals in excess of 30 inches in parts of Wilmington and almost 36 inches (35.93 inches) of rain recorded in Elizabethtown. Based on reported climatology for coastal North Carolina, the rainfall associated with Hurricane Florence can be classified as a 1-in-1000 year event, i.e., having an annual probability of occurrence of 0.001. As of September 21, 14 rivers in North Carolina were still experiencing major flooding.

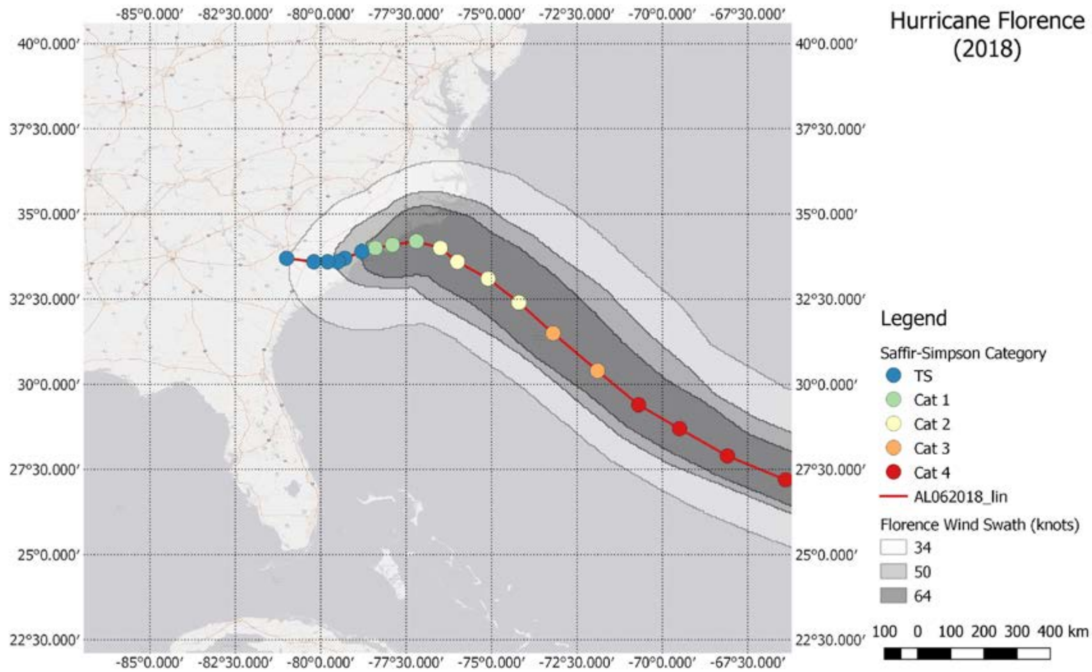

Figure 1: Hurricane Florence track and wind swath (data source: National Hurricane Center)

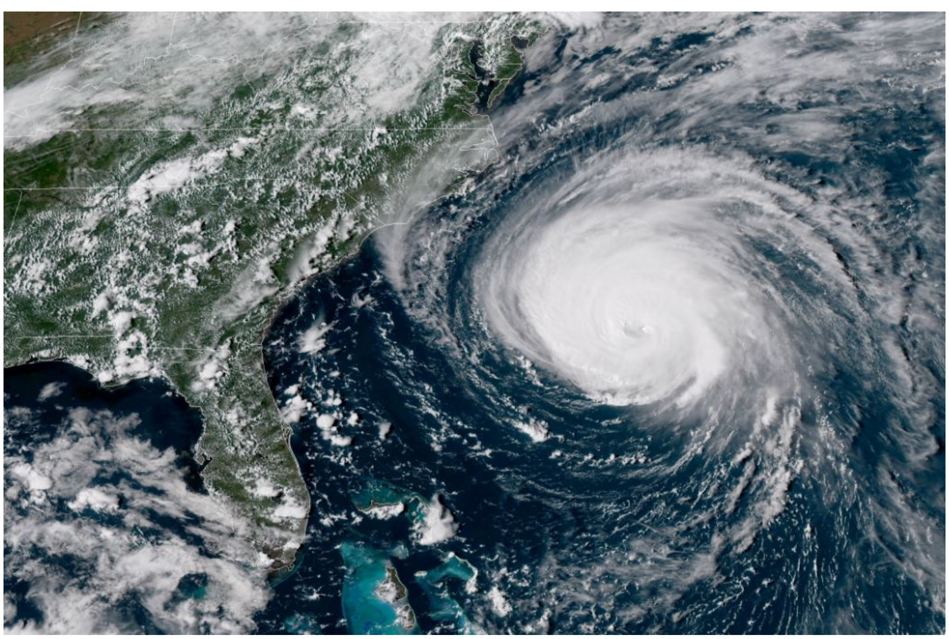

Figure 2: NOAA Satellite imagery of Hurricane Florence on September 12, 2018 (Category 3)

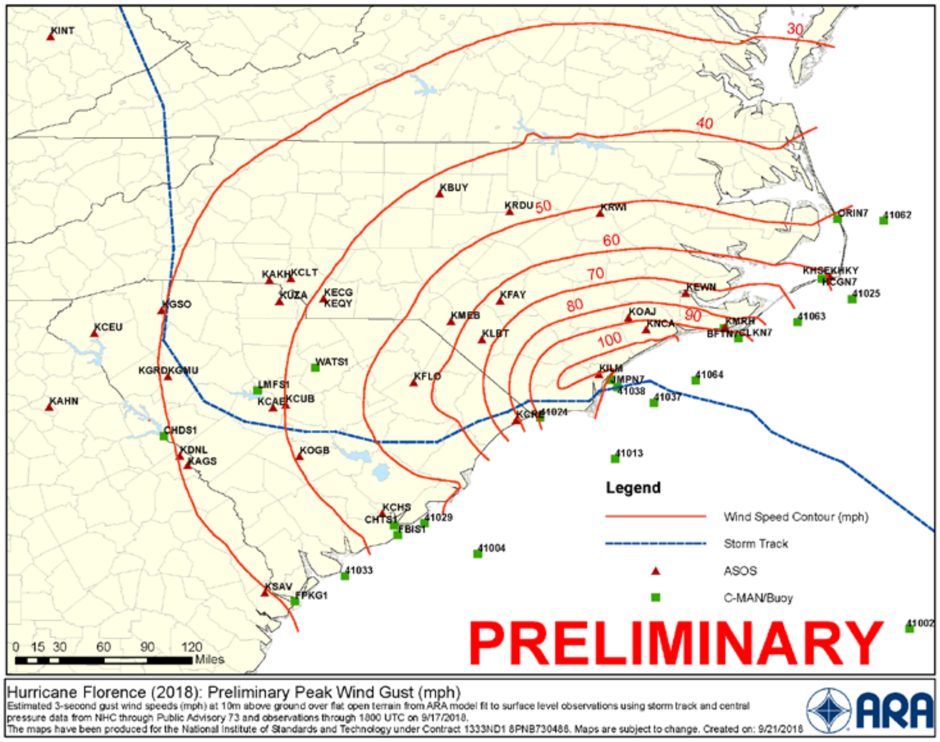

Figure 3: Preliminary peak wind gust (3-second average, 10 m height, open terrain) as estimated by ARA (Courtesy of NIST)

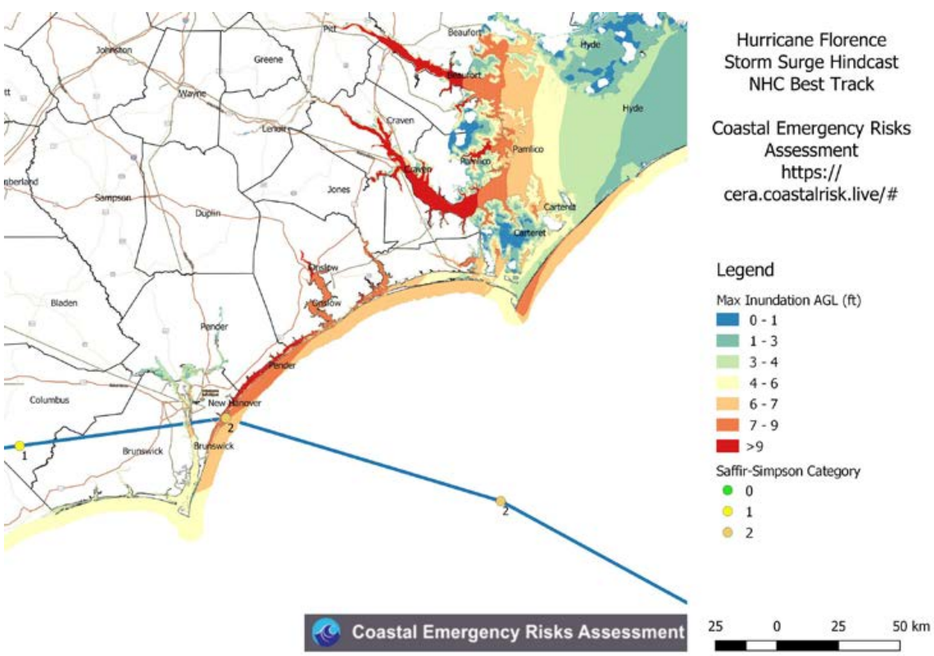

Figure 4: Maximum storm surge inundation above ground level (or above mean sea level if over water) caused by Hurricane Florence, as indicated by ADCIRC simulations based on hindcast of the NHC best track by the Coastal Emergency Risks Assessment tool led by Louisiana State University (https://cera.coastalrisk.live/).

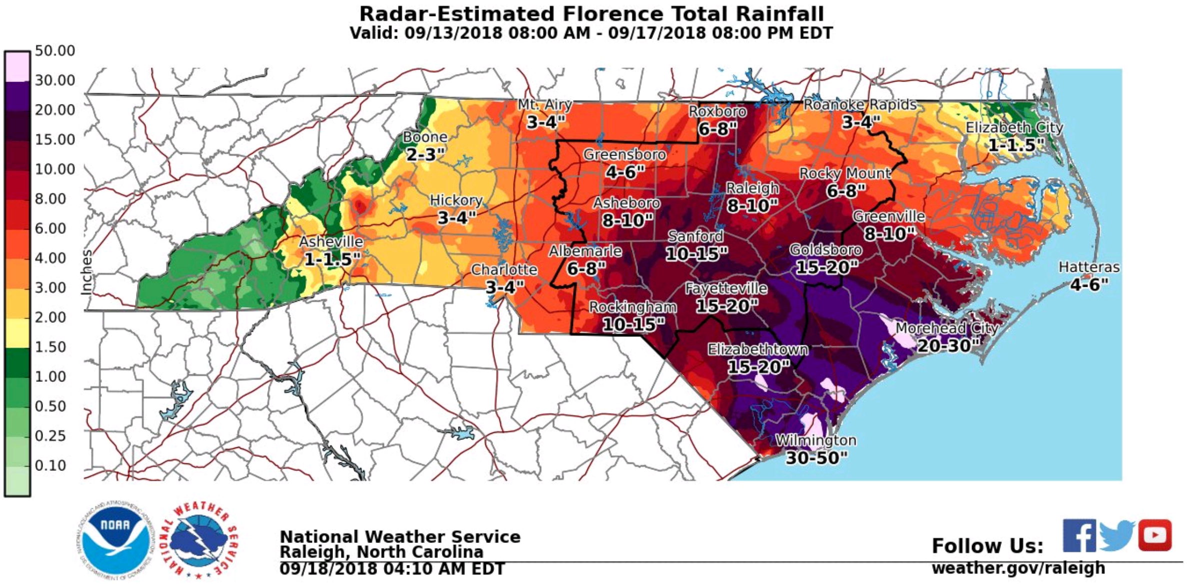

Figure 5: Estimated Total Rainfall in North Carolina (National Weather Service: https://twitter.com/NWSRaleigh)

StEER Response Strategy

As Florence struck prior to StEER's full operationalization, a rapid mobilization was conducted with open calls for enlistment days before Florence's landfall, which resulted in 100 volunteers. In parallel, StEER worked to review inventory data in the landfall region, identifying potential clusters where damage assessments could capture a range of typologies and ages of construction under comparable hazard exposure, based on projected wind and storm surge levels. Real-time collaboration with researchers from the University of Florida and University of Illinois Urbana-Champaign, enabled the strategic placement of meteorological instruments at locations with different exposures near the eventual path of the eye wall. Clusters were anchored around these tower placements, as well as near transects where wave gauges were installed.

Based on prior event experience and preferences, volunteers were offered positions on one of three StEER Teams:

- **Coordination and Support Team (CST)** was comprised of individuals without prior field experience (as well as students who volunteered through a crowdsourced effort at the StEER nodes) to compile data on access and restrictions in targeted areas. StEER took advantage of EERI's Virtual Earthquake Reconnaissance Teams (VERTs) as an extension of the CST to assemble event information and preliminary impact assessments from public sources.
- **Field Assessment Teams (FATs)** were formed by invitations to individuals with prior field experience and expertise relevant to this type of event. FATs were used to rapidly gather essential data only visible on the ground, with the understanding that these will be enriched with additional sources of data through aligned StEER efforts.
- **Virtual Assessment Teams (VATs)** were formed to lead report authorship, enrich FAT data with other information gleaned from inventory and high-resolution imagery, and participate in quality assurance and data cataloging processes.

This report focuses on FAT-1, composed of regional experts capable of reaching the landfall area as soon as access safely possible. FAT-1 was tasked with swiftly working along the coastline of the affected area to examine clusters along the barrier islands and informing targets of interest to StEER FAT-2 and other NSF RAPIDs interested in conducting high-fidelity data collection, as well as other non-NSF efforts like FEMA MAT. FAT-1 specifically:

- gathered samples of damage to buildings and other infrastructure with emphasis on velocity-induced damage due to wind and storm surge using a combination of door to door (D2D) damage assessments and unmanned aerial surveys (UASs)
- recorded spot evidence of hazard intensity (e.g., high water marks)
- established restrictions and accessibility constraints for future teams

FAT-1 collected data September 20-22, 2018 from Atlantic Beach down to Wrightsville Beach, with D2D assessments of over 260 buildings.

Local Codes & Construction Practices

North Carolina's history of major storms prompted one of the US's earliest codification of hurricane design standards, preceded only by the South Florida Building Code. The state's early adoption of mitigation measures has been a key factor in minimizing hurricane losses. The North Carolina Building Code (NCBC) and the North Carolina Residential Code (NCRC) are the currently-enforced codes, last revised in 2012 based on the 2009 publications of the International Building Code and International Residential Code, respectively, with amendments developed by the North Carolina State Building Code Council. Figures 6 and 7 display the design wind speed maps from the two governing codes.

It is worth noting that ASCE 7–10 revised the design wind speeds in hurricane zones yielding contours along the North Carolina coast that are approximately 10% lower than the previous standard (and resulting in roughly 20% lower design forces). This is effectively counterbalanced by accompanying requirements to increase the wind design forces on buildings within the first 600 feet of the shoreline. Coastal buildings greater than 600 feet from shoreline will see still see a reduction in the design forces due to the former revision -- an effect that gradually reduces moving inland to about Raleigh, at which point ASCE 7-10 design loads are consistent with the previous version of the standard. These changes have been approved by the NC Building Code Council and will take effect January 1, 2019.

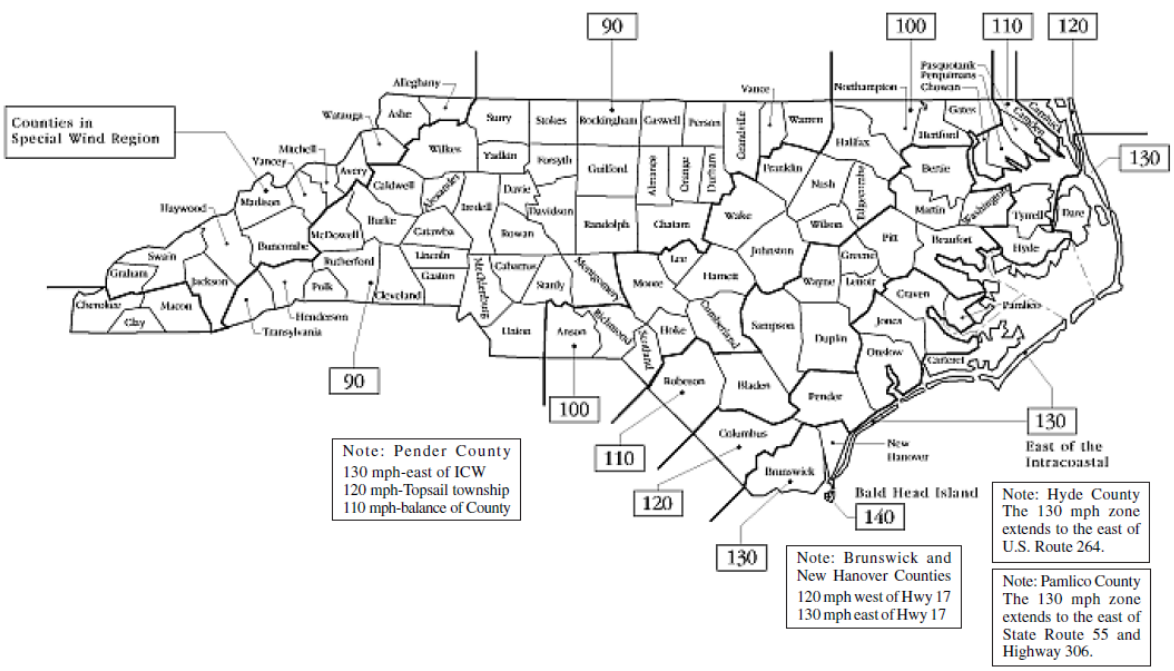

Figure 6: North Carolina Basic Wind Speeds for Fifty-Year Recurrence Interval. (Figure R301.2(4) in NCRC)

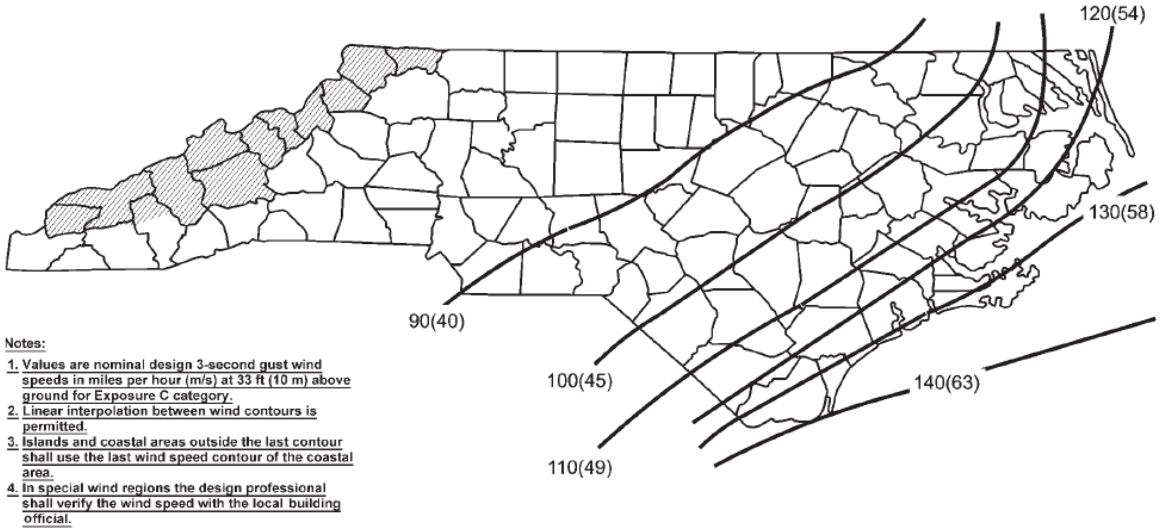

Figure 7: North Carolina Basic Wind Speed Map (Figure 1609 in NCBC)

Construction practices along the barrier islands have transitioned from the modest beach houses constructed prior to the 1980s toward much larger, luxury homes, particularly after the loss of many properties in the impacted area following Hurricane Fran. The 1960s marked a transition on the barrier islands to improved roof to wall connections and pile-supported houses elevated 8 feet above grade with under-house parking, 10 to 20 years earlier than NFIP-inspired actions in other states. 1985 marked a major revision to the hurricane-resistant building code provisions, particularly with respect to pile depths at the oceanfront. Improved roof to wall connection requirements extended beyond the barrier islands around 1995. A similarly noteworthy mitigation requirement took effect in 2009 (and is relevant to the impacted area which falls within NCBC/NCRC's wind-borne debris region) with new requirements for impact-rated glazing or minimum thickness protective panels over openings. (See the Appendix for a chronology of coastal construction practices and codification in North Carolina.) Since 2011, insurance rate credits have been available for wind-resistant features in coastal buildings. These focus on opening protection and roof shape, as well as promoting the IBHS FORTIFIED Construction tiers. These discounts were available in the impacted area; private insurance companies and the state-mandated wind pools are required to offer them.

Reconnaissance Methodology

FAT-1 employed door to door (D2D) damage assessments, as well as coordinated unmanned aerial surveys (UAS) to gather the data referenced in this report, as now summarized. As D2D damage assessments were collected at predefined clusters spanning from Atlantic Beach down to Wrightsville Beach, 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 FAT members to select assessment forms customized for buildings, non-buildings, or hazard indicators.

FAT 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.

A large portion of D2D data enrichment comes from VATs analyzing data submitted by FATs once the file synchronizes with the backside Fulcrum database. VATs are charged with 1) creating uniform damage rating standards from the variable assessments of individual FAT investigators, 2) conducting a detailed QA/QC process, 3) enriching each entry with more detailed classification of the structure and assessments of overall/component damage due to wind and storm surge, and 4) oversee the migration of this data into DesignSafe in accordance with uniform data standards.

Unmanned Aerial Surveys

Two different unmanned aerial vehicles were used to conduct surveys for FAT-1: a sensefly eBee fixed wing with S.O.D.A. camera and DJI Phantom 4 Pro quadcopter with P4P camera. Quadcopter surveys operated at an altitude of 125-160 feet, with overlap of 70-80%, while the fixed wing unit operated at 200 feet with 70% overlap. UASs were conducted at Atlantic Beach, Emerald Isle, Pine Knoll Shores, North Topsail Beach, Surf City and Holly Ridge/Topsail Beach.

Observations by Region

Observations of damage and conditions in the regions assessed by FAT-1 are now summarized. It should be noted that within a week of the storm, homeowners and businesses in the landfall region were actively assessing damage, tarping roof damage, clearing debris and in many instances re-establishing normal modes of operations. Transportation in the region was improving, though many roads in Duplin, New Hanover and Pender counties are still flooded; the Neuse and Cape Fear rivers remain difficult to cross. Although water is receding on some roads, closures are still in effect (https://tims.ncdot.gov/tims/). While there were initial gas shortages, by the time FAT-1 conducted its surveys, access to fuel was no longer an issue. Cellular coverage remains intermittent, based on provider, but does not pose significant barriers to survey and recovery efforts.

Atlantic Beach

D2D and UAV assessments were conducted in Atlantic Beach by FAT-1 on September 20, 2018 near the intersection of West Atlantic Boulevard and South Durham Avenue as well as along West Boardwalk. Fifteen residential buildings were surveyed in the D2D assessment; those sustaining damage had preliminary overall wind damage ratings of minor (N=5), moderate (N=6), and severe (N=1). Preliminary analysis of D2D data in the sampled clusters indicates damage predominantly driven by wind and largely confined to the building envelope, with loss of vinyl siding (Fig. 8) and asphalt shingles (up to 30% cover loss) being most prevalent. No damage was observed in sampled properties with metal roofs.

Accessibility: As of September 20, Highway 70 is closed in Kinston near the intersection of Hwy 258 South (near Neuse Sport Shop) due to rising floodwaters from the Neuse River. This closure could last up to 5-6 days. Town-wide curfews in Indian Beach, Atlantic Beach and Pine Knoll Shores have all been lifted. The State of Emergency Declaration remains in effect in Atlantic Beach until further notice.
Site Conditions: As of September 20, Harkers Island is still without power and is running low on supplies. Electrical power has been restored, though phone service, cable tv and internet services remain sporadic. The town has pre-arranged debris removal contractors beginning disposal services the week of September 24.

Figure 8: Loss of wall cover at residence in Atlantic Beach

Emerald Isle/Pine Knoll Shores

D2D and UAV assessments were conducted in Emerald Isle by FAT-1 on September 20, 2018 at three locations: Pine Knoll Shores near the intersection of Salter Path Road and Pine Knoll Boulevard, Emerald Isle near the intersection of Ocean Drive and Connie Street, and near the intersection of Emerald Drive and Mangrove Road. D2D surveys included 66 residential, 6 commercial, 1 government, and 2 hotel buildings were surveyed; those sustaining damage had preliminary overall wind damage ratings of minor (N=28) and moderate (N=18). Preliminary analysis of D2D data in the sampled clusters at Pine Knoll Shores and Emerald Isle near Ocean Drive and Connie Street indicates wind-induced damage again largely confined to the building envelope, with loss of roof shingles being most prevalent. Near Emerald Drive and Mangrove Road, the impacts of water penetration were also observed with loss of roof shingles, siding, and soffits. Vinyl siding failures, particularly those installed over existing wood panel siding (Fig. 9), were common.

Figure 9: Loss vinyl siding installed over wood panel siding and shingle loss near roof ridge in Emerald Isle

Accessibility: US 70 is closed due to rising waters in the Neuse River; however, it is now possible to travel from the Raleigh area to Emerald Isle via I-40 and NC 24. Flood waters have been mostly cleared from Coast Guard Road and it is now possible for vehicles to travel all the way to The Point. Emerald Isle Bridge is open to the public from 8 am to 8 pm (re-entry permit not necessary). As of Friday, September 21st at 6 am, the town-wide curfew has been lifted.
Site Conditions: As of early Thursday morning, approximately 84% of Carteret-Craven Electric consumers in the Isle had power restored, with full restoration projected by September 23. Water conservation remains in effect. Internet service has not been restored in all locations. Contractors have begun collecting construction and demolition debris. The town's primary focus remains the resolution of storm water flooding, continuing efforts to pump significant floodwaters using 28 storm water pumps. Post-storm conditions are best summarized by this volunteer drone footage: https://www.emeraldisle-nc.org/hurricane-florence--september-2018.

North Topsail Beach

D2D and UAV assessments were conducted in North Topsail Beach by FAT-1 on September 21, 2018 primarily between 9th Avenue and 18th Avenue off of Island Drive, with a few additional residential buildings on Island Drive northeast of Hunter Health Drive. A total of 49 residential buildings were surveyed in the D2D assessment; those sustaining damage had preliminary overall wind damage ratings of minor (N=26), moderate (N=11), and severe (N=2). Preliminary analysis of D2D data in the sampled clusters indicates damage predominantly driven by wind and rain penetration, largely confined to roof shingles and siding. Some of the more notable storm surge impacts were observed along ocean-front properties in this area, with erosion, damage to decks, staircases, and finishes in under-house parking areas (Fig. 10).

Figure 10: Property in North Topsail Beach with erosion and surge-induced property damage, note loss of vinyl siding though soffits and metal roof performed well.

Accessibility: Topsail Island reopened to residents on September 20 at 9 am; FAT-1 was allowed access on September 21. All of Topsail Island remains under a State of Emergency with reaffirmed restrictions on September 21, with designated re-entry traffic patterns and checkpoints. Topsail Island is currently only open to residents, certified general contractors and licensed insurance adjusters; the general public and short term rentals will not be allowed on the island until further notice. Reports on September 22 indicated that access to Topsail Island may be denied without credentials and legitimate business on the island. Curfew (7 pm-7 am) remains in effect until September 24 for those remaining on the island. All public beaches are closed until further notice.
Site Conditions: As September 22, the boil water advisory has been lifted and water production is back to 99% capacity. Small scattered power outages remain and electrical assessments have been completed. Internet connections remain spotty in the area. Hurricane

debris collection has not yet initiated. Post-event drone footage is available for overall impression of conditions at North Topsail Beach: https://youtu.be/o3UsWL2Oi2k.

Surf City

D2D and UAV assessments were conducted in Surf City by FAT-1 on September 21, 2018 between Greensboro Avenue and New Bern Avenue. The D2D assessment encompassed 19 residences, 5 businesses, 1 government building, and 3 hotels; those sustaining damage had overall wind damage ratings of minor (N=12), moderate (N=4), and severe (N=3). Preliminary analysis of D2D data in the sampled clusters indicates wind as the primary instigating hazard, largely confined to loss of roof shingles, flashing and siding (Fig. 11) with evidence of wind-driven rain penetration. No damage was observed in residential homes with metal roofing.

Figure 11: Loss of wood panel siding in Surf City

Accessibility: Topsail Island reopened to residents on September 20 at 9 am; FAT-1 was allowed access on September 21. All of Topsail Island remains under a State of Emergency with reaffirmed restrictions on September 21, with designated re-entry traffic patterns and checkpoints. Topsail Island is currently only open to residents, certified general contractors and licensed insurance adjusters; the general public and short term rentals will not be allowed on the island until further notice. Reports on September 22 indicated that access to Topsail Island may be denied without credentials and legitimate business on the island. Curfew (7pm-7am) remains in effect until September 24 for those remaining on the island. All public beaches are closed until further notice.

Site Conditions: As of September 22, the boil water advisory for Surf City has been lifted. Internet access and power have been restored, and hazardous debris has yet to be removed. Post-event drone footage is available for overall impression of conditions on Topsail Island:

https://www.youtube.com/watch?v=Sv88SKEFttU&feature=youtu.be.

Topsail Beach/Holly Ridge

Preliminary municipal assessments indicate that most of the damage to structures in Topsail Beach was limited to roofing, shingles and siding, with likely interior flooding on lower level floors. D2D and UAV assessments were conducted in Topsail Beach/Holly Ridge by FAT-1 on September 21, 2018 near Ocean Boulevard to the Banks Channel between Clark Avenue and McLeod Avenue. D2D assessments included 55 residences and 1 hotel; those sustaining damage had preliminary overall wind damage ratings of minor (N=22), moderate (N=10), severe (N=4) and destroyed (N=1). Preliminary analysis of this data indicates damage predominantly driven by wind (N=40), flood (N=16) and rain (N=12) and largely confined to building envelope with roof damage and siding loss being the most prevalent (Fig. 12). A number of the buildings in this surveyed cluster had recently replaced roofs (1-3 years ago), enabling side-by-side comparisons with roofs of older vintage under similar wind speeds.

Figure 12: Damaged residence in Topsail Beach with siding loss and soffit damage

Accessibility: Topsail Island reopened to residents on September 20 at 9 am; FAT-1 was allowed access on September 21. All of Topsail Island remains under a State of Emergency with reaffirmed restrictions on September 21, with designated re-entry traffic patterns and checkpoints. Topsail Island is currently only open to residents, certified general contractors

and licensed insurance adjusters; the general public and short term rentals will not be allowed on the island until further notice. Reports on September 22 indicated that access to Topsail Island may be denied without credentials and legitimate business on the island. Curfew (7pm-7am) remains in effect until September 24 for those remaining on the island. All public beaches are closed until further notice.
Site Conditions: Debris removal initiated on September 24. Phone and internet services have not been restored, but water is in service. Post-event drone footage is available for overall impression of conditions on Topsail Island: https://www.youtube.com/watch?v=Sv88SKEFttU&feature=youtu.be.

Wrightsville Beach

D2D assessments were conducted in Wrightsville Beach by FAT-1 on September 22, 2018 near the S. Banks Channel Bridge between East Charlotte St and Oceanic St. The D2D survey in this region included 25 residences and 3 commercial buildings. Those sustaining damage had preliminary overall wind damage ratings of minor (N=12) and moderate (N=2). Preliminary analysis of D2D data in the sampled clusters indicates damage predominantly driven by wind with minor flooding and was largely confined to the building envelope. A number of tile roof failures were observed at the northern end of Wrightsville Beach (Fig. 13).

Figure 13: Damage to tile roof in Wrightsville Beach

That same day, FAT-1 also gained access to Figure Eight Island, a nearby private community, following a tip that a pair of adjacent oceanfront homes at south end of Figure Eight Island that sustained significant roof damage. Both properties experienced beach erosion sufficient to expose foundation elements (Fig. 14b) and significant structural damage at the northeast corner (ocean-facing) of their respective roofs (Fig. 14a,c,d). Property B in Figure 14 also appears to have had rolling storm shutters dislodged during the failure (Fig. 14 d).

(a)


(b)


(c)


(d)


Figure 14: Damage to pair of oceanfront residences on Figure Eight Island: (a) NOAA Aerial imagery of surveyed properties; (b) exposed foundation elements due to erosion at Property A; structural wind damage to northeast corner of roofs on (c) Property A and (d) Property B where depth of erosion is also evidenced by exposed paint boundary on timber supports

Accessibility: The curfew for Wrightsville Beach has been rescinded and no restrictions are placed on movements in the area. All lanes of US 421 South Bound and Northbound are closed near the Pender/New Hanover County line. The road is expected to open again November 1st. SR-1310 in Hightsville is closed due to a reported washout. A number of other roads are currently impassable due to flooding:

- US-421 north of Wilmington
- US-117 over the NE Cape Fear River near castle Hayne (closure is between NC-133 on the North side of the river and Holly Shelter Road on the South side); likely to re-open by September 25th.
- SR-99 near US-74
- SR-1339 near Big Neck Rd NW

Site Conditions: It is anticipated that the majority of the power to the island will be on beginning September 25th. The town has asked its residents to conserve and boil water until all sewer and water infrastructure can be brought back to normal operating capacity.

Recommendations for Further Study

FAT-1 primarily focused assessments on areas of the North Carolina barrier islands that experienced some of the highest estimated wind speeds in Hurricane Florence and where storm surge was also present. Preliminary review of assessments logged by the team in these areas, in addition to observations by the teams as they traveled throughout the impacted areas, have led to the following recommendations for future study.

For high wind impacts:

1. It is recommended that damage to building envelopes on mainland properties be formally assessed. Damage was evident along the corridor of NC 24 from Jacksonville to the Newport area, particularly for the houses near Bogue Sound, e.g, Cedar Point. These areas are not within the wind-borne debris regions of the NC building code and also have lower design wind speeds, potentially enhancing the damage rates.
2. It is recommended that formal structural engineering assessments of potential cyclone-induced tornado tracks be conducted. Envelope damage is evident along US 70 between Newport and New Bern, including some significant masonry parapet and roof damages around Havelock Elementary School. Tree damage is particularly noticeable along this corridor (Croatan National Forest) with pine trees snapped 5-20 ft from the ground (Fig. 15) and uprooted deciduous trees. The NWS has not identified a tornado at this location based on current records.
3. It is recommended that further study be conducted on the effects of high wind and rainfall durations. The large wind field of Hurricane Florence combined with the slow forward translation speed resulted in areas experiencing hurricane level wind speeds and extreme rainfall rates for sustained periods of time. Fatigue failures, failure propagation in roof cover and wall cladding systems, and tree-fall may have been exacerbated by long-duration winds. The prolonged exposure to high winds in combination with extreme rainfall rates likely enhanced wind-driven rain deposition rates to the interior of buildings, leading to greater interior losses and economic impacts.
4. It is recommended that further study be conducted on the performance of gas canopy stations, which were observed to have failed at many locations throughout the Hurricane Florence wind field, and often disproportionately to observed damage to surrounding structures. Failures of these structures further inhibit distribution of critical gasoline products to consumers in the days following hurricane landfall.
5. It is recommended that further study be conducted on the high failure rates of wall cladding systems that were observed in the FAT-1 survey clusters, despite the wind speeds that were well-below design levels. Expectations of failure of the various systems should be related to the manufacturer-designated design wind pressure and related product approvals.

For storm surge impacts:

1. Further assessments of the sediment transport and scour around structural elements along the barrier islands could be useful for calibration of sediment transport models. Flow depth measurements will be available along three transects on Topsail Island that may

assist in estimation of wave height and celerity. Depending on availability of pre-hurricane dune and beach profiles, along with scour exposure of structural elements, it may be possible to estimate the amount of sediment transport and scour that have occurred.

2. It is recommended that further assessments be conducted of potential storm surge impacts in the inland estuaries and other areas west of the intercoastal waterway. Potential sites include:
    a. Wilmington, NC along HWY 1100, where a wastewater treatment plant, fuel storage yards, and container handling yard and wharf were potentially impacted by storm surge along the Cape Fear river.
    b. Silver Lake, NC in Hanover County, where many wooden piers appear to be damaged or destroyed due to storm surge.
    c. Sites along the Neuse River between Cherry Point and New Bern.
    d. Sites along the Pamlico River, which experienced large surge in Blount's Bay between Chocowinity and Aurora with approximately 40% of wooden piers lost due to surge.

Figure 15: Snapped pine trees along US 70 between Havelock and New Bern

Appendix

Summary of history and evolution of the building codes and coastal construction practice in North Carolina	
Year/ period	**Summary of changes to building code**
Pre-1950s	Coastal buildings in NC were constructed just like inland buildings with low floor elevation on slab foundations or short, unreinforced piers.
1965	A statewide building code was adopted for residential construction, which institutionalized the use of piling. ● Initial hurricane standards had to be adopted locally for enforcement. Most beach areas adopted the code quickly. ● The code included a provision for hurricane-resistant construction for barrier islands (piling and roof to wall connections). ● Requirement for piling foundation and specific elevation for oceanfront buildings was implemented. ● Pilings required to extend 8 ft below grade. ● Most new buildings after 1965 met or exceeded code requirements.
Approx 1976	A minimum wave height threshold is implemented for highest risk areas (V-zones) along the coast based on the National Flood Insurance Program (NFIP) regulations. ● Piling foundations required for all new buildings based on depth-limited 3-foot wave or larger. ● The minimum wave height threshold was based on a report by the Galveston District Corps of Engineers (1975). ● Finishings and living space prohibited below elevated floors. Areas below elevated floors can be used for parking, storage, and building access. Only break-away walls allowed.
1979	The NC Coastal Area Management Act (CAMA) implemented a statewide oceanfront setback line. ● CAMA requires buildings to be located at least 30 times the erosion rate from beach vegetation line (minimum 60 ft). ● Construction of most permanent erosion-control structures was prohibited for buildings constructed after 1979.
1985	● Prohibition on most erosion control structures was broadened to include buildings constructed prior to 1979. ● Ocean setback distance for commercial and multi-family buildings doubled to 60 times the erosion rate.
1985	NC Building Code (NCBC) Council completely revised provisions for hurricane-resistant buildings.

	• Piling penetration depth for most oceanfront buildings increased from 8 ft to the smallest of -5 ft NGVD and 16 ft.
1993	CAMA required all new oceanfront buildings to be moved farther landward if threatened by erosion for more than two years.
2002	North Carolina adopted the International Building Code (I-Codes) published in 2000.
2006	NCBC Council implemented the I-Codes wind-blown debris protection requirement • The requirement only applies to zones within 1,500 ft from the ocean. • The requirement only applies to new houses. Many owners of existing buildings chose to install protection. • The decision was partly based on the observations of low levels of debris damage in recent hurricanes. • The NCBC Council rejected a request for an option that will allow local governments to set higher standards.
2009	A revised NCBC went into effect 1/1/2009 based on 2006 I-Codes.
2009	Code revision expanded wind-borne debris zone to the barrier island in the north and seaward of the Intracoastal Waterway, south of Cape Lookout.
2011	Wind insurance initiatives were implemented (approved in 2009) but have not been widely applied, with recent efforts by NC wind pools in the last two years to promote policy riders that may have impacted performance in Florence.
2012	NC Building Code (NCBC) and NC Residential Code (NCRC) were last revised. • NCBC and NCRC are based on I-Codes and International Residential Code (IRC) (2009). • Basic wind speeds in NCBC adopted from ASCE 7. • Windows in buildings in wind-borne debris regions required to have glazed openings. • Glazed openings required to meet the requirements of the Large Missile Test of ASTM E 1996. • Garage door glazed openings required to meet ANSI/DASMA 115 standards or other approved standards. • Wood structural panels with a minimum thickness of 7/16-in and maximum span of 8 ft can be used for opening protection in one- and two-story buildings. • According to NCBC, glazed openings more than 30 ft above grade are required to satisfy only the small missile test of ASTM E 1996.
2015	NCBC Council deleted the requirement in 2009 IRC that requires wood storm shutters to be permanently attached to a building.
2019	Adoption of ASCE 7-10 design wind speeds, with reductions of approximately 10% to the design wind speed at coastal contours, but requiring increase in design wind loads for structures within first 600 feet of coastline.

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- Camila Gonalez Flores (University of Notre Dame) for her administrative support in organizing shared file systems, personnel databases, and web resources for this effort.

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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 Florence 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.