HURRICANE DORIAN

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EARLY ACCESS RECONNAISSANCE REPORT (EARR)

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PREFACE

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 (see https://www.steer.network for more details). *StEER builds societal resilience by generating new knowledge on the performance of the built environment through impactful post-disaster reconnaissance disseminated to affected communities.* StEER achieves this vision by: (1) deepening structural engineers' **capacity** for post-event reconnaissance by promoting community-driven standards, best practices, and training, as well as their understanding of the effect of natural hazards on society; (2) **coordination** leveraging its distributed network of members and partners for early, efficient and impactful responses to disasters; and (3) **collaboration** that broadly engages communities of research, practice and policy to accelerate learning from disasters. StEER works closely with other extreme event reconnaissance organizations and the Natural Hazards Engineering Research Infrastructure (NHERI) to foster greater potentials for truly impactful interdisciplinary reconnaissance after disasters.

Under the banner of NHERI's CONVERGE node, StEER works closely with the wider Extreme Events Reconnaissance consortium including the Geotechnical Extreme Events Reconnaissance (GEER) Association and the networks for Nearshore Extreme Event Reconnaissance (NEER), Interdisciplinary Science and Engineering Extreme Events Research (ISEEER) and Social Science Extreme Events Research (SSEER), as well as the NHERI RAPID equipment facility and NHERI DesignSafe CI, long-term home to all StEER data and reports. While the StEER 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 for overseeing the design and operationalization of the network and representing StEER in the NHERI Converge Leadership Corps.
- **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 suitable for re-use by the community.

ACKNOWLEDGMENTS

This material is based upon work supported by the National Science Foundation under Grant No. CMMI 1841667. Any opinions, findings, and conclusions or recommendations expressed in this material are those of StEER and do not necessarily reflect the views of the National Science Foundation. All authors and editors listed on the cover page participate as volunteer professionals. Thus, any opinions, findings, conclusions or recommendations expressed herein are those of the individual contributors and do not necessarily reflect the views of their employer or other institutions and organizations with which they affiliate.

Data discussed in this EARR was collected in part using equipment provided by the National Science Foundation as part of the RAPID Facility, a component of the Natural Hazards Engineering Research Infrastructure, under Award No. CMMI: 1611820. StEER is grateful for the partnership with the NHERI RAPID Equipment Facility at the University of Washington and the efforts of Jeff Berman and Joe Wartman, as well as the support of Catlin Bourassa and Jacqueline Peltier in making this challenging and swiftly mobilizing mission possible.

Special thanks also go to Steve Pece and his associates for their active participation and outstanding logistical support in the FAST-1 deployment, including securing transportation, lodging, and other resources. His services and resources were invaluable to the success of this mission and the safety of our team. We are especially thankful for his proactive outreach to StEER, which made this mission possible. Special thanks also to Spatial Networks and Fulcrum Community, for providing an efficient platform to both capture and share high quality reconnaissance datasets. We also thank StEER FAST-2 member Andrew Kennedy for his efforts to secure high-resolution satellite imagery in support of FAST-1's mission.

The sharing of videos, damage reports and briefings via Slack by the entire NHERI community was tremendously helpful and much appreciated. StEER recognizes the efforts of the DesignSafe CI team who continuously supported and responded to StEER's emerging needs.

For a full listing of all StEER products (briefings, reports and datasets) please visit the StEER website: https://www.steer.network/products

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EXECUTIVE SUMMARY

Hurricane Dorian struck the northwest Bahamas with remarkable and long-lasting ferocity, attaining estimated maximum gust wind speeds exceeding 200 mph and storm surge upwards of 20 ft above mean sea level. At time of publication, the official death toll from Dorian in the Bahamas was 61, with 608 still listed as missing. Thousands of people are displaced and will likely remained displaced for long periods of time, if not permanently, due to the impacts and challenges of recovery. The Red Cross estimated nearly 45% of houses on the affected islands (approximately 13,000 houses) were severely damaged or destroyed. Preliminary economic losses are estimated at $7 billion, or approximately 57% of the entire 2017 GDP for the Bahamas. This is the most recent and devastating of a pattern of catastrophic hurricane losses throughout the Caribbean archipelago for much of the 20th and now 21st centuries. Dorian reinforces patterns observed in Dominica (from Hurricane Irma, 2017), Puerto Rico (2017's Hurricane Maria) and even going back to 1932, when the Great Abaco Hurricane (Category 5, minimum central pressure of 934 mb) produced extreme winds and storm surge similar to what occurred in Hurricane Dorian. Some islands have been struck by hurricanes in 15 to 30 year cycles, causing recurring vicious cycles of damage.

This Early Access Reconnaissance Report (EARR) is StEER's second product from this event and provides an overview of Hurricane Dorian, StEER's event response, and preliminary findings based on the data and observations generated by its first Field Assessment Structural Team (FAST-1). FAST-1 was led by structural engineer Justin Marshall (Auburn University), wind engineer Daniel Smith, (James Cook University/University of Florida), and operations engineer Andrew Lyda (University of Washington NHERI RAPID facility). Steve Pece of Pece of Mind Environmental, Inc. provided personal mission logistics to rapidly access to the islands. The FAST-1 deployed between 24-26 September 2019, utilizing Door-to-Door assessments and Applied StreetView imaging across Marsh Harbour and Treasure Cay, on Great Abaco Island, to document structural performance of buildings and other structures.

In general, FAST-1 observed widespread damage across all building typologies, but there was also a wide range of building performance that contradicted the narrative of near-universal destruction being reported in the international media:

- Successes are common, with success being defined as the structural system and the majority of the building envelope still intact with little to no evidence of damage. A cross-section of residential, institutional, and commercial buildings performed quite well structurally, despite the extreme conditions, providing critical learning opportunities for enhancing hurricane resilience.
- Unfortunately, buildings that survived structurally were often subjected to storm surge and rainwater ingress that destroyed interior contents.
- Wave action on coastal structures in combination with the high winds produced the most consistent levels of structural damage, with many buildings washed away completely. FAST-1 observed that the critical failure in the structural load path in these instances was often the limited capacity of the attachment of the superstructure to the foundation piles or piers.

Finally, all observations and findings provided herein are based on the limited scope of FAST-1. Specific recommendations of areas worthy of further investigation by the community are offered at the conclusion of this report. While the damage assessments discussed herein are based largely on the judgement of the authors and can be further enriched as data becomes available.

1.0 Introduction

Hurricane Dorian struck the northwest Bahamas with remarkable and long-lasting ferocity, with maximum gust wind speeds estimated to exceed 200 mph and storm surge upwards of 20 ft above mean sea level. Kijewski-Correa et al. (2019) summarized the storm track and general characteristics of the storm and its impacts in the Bahamas and the United States. At this time, it is apparent that Dorian is the most intense hurricane to strike the Bahamas (based on climatological records that include at least 200 hurricanes as shown in Figure 1.1), and the worst weather disaster in the history of the Bahamas.

At time of publication, the official death toll from Hurricane Dorian, as reported by the Government of the Bahamas (GoB), officially remains at 61. Of those 50 fatalities, 52 occurred on Abaco Island and 9 were on Grand Bahama Island (RBPF, 2019). However, 608 people are still reported missing, so the number of fatalities is still likely to rise (TWC, 2019). The initial estimate of 2,500 people missing was reduced to 1,300 and then again down to 608 after accounting for those that evacuated to Nassau, the capital city of the Bahamas, and to Florida. The Red Cross estimated approximately 13,000 houses were severely damaged or destroyed (nearly 45% of the entire population of homes), and economic losses have been given a preliminary estimate of $7 billion (World Food Programme, 2019). There are approximately 70,000 survivors in the worst hit areas that are in need of basic necessities such as food and shelter, as there is very little left on the islands. Thousands of people are displaced and will likely remain displaced for long periods of time, if not permanently, due to the impacts and challenges of recovery. The latest reports estimate that 5,500 people have been evacuated to Nassau, while thousands of others are still waiting to evacuate. The mass evacuation to Nassau has caused a housing shortage, leaving many still in need of food and shelter (Forbes, 2019). CBS News has reported that survivors without U.S. visas are having difficulties evacuating to Florida.

The disaster caused by Hurricane Dorian's extreme winds and storm surge impacts necessitated a rapid response by the Structural Extreme Events Reconnaissance (StEER) network to assess the impacts of this extreme storm and advance knowledge that can be used to mitigate or even prevent future disasters. StEER was particularly motivated to activate this response due to the historic nature of this storm's landfall in the Bahamas, and the diverse typologies that were impacted by a gradient of hazard conditions. The primary objective of StEER's response to Dorian is the swift capture of perishable data through a coordinated strategy involving a suite of technologies to improve our understanding of the performance of structures under extreme hurricane impacts. This Early Access Reconnaissance Report (EARR) is the second product for this event from StEER, following the Preliminary Virtual Reconnaissance Report (PVRR) (Kijewski-Correa et al. 2019), and focuses on the mission and findings of the first Field Assessment Structural Team (FAST-1).

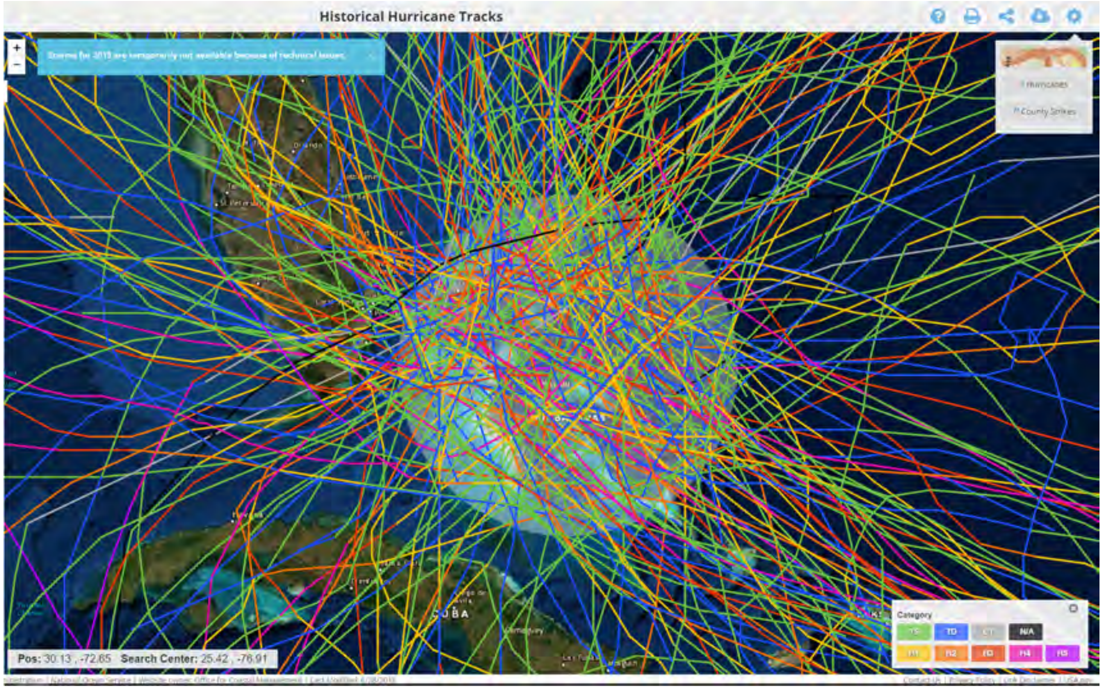


Figure 1.1. Historical cyclone tracks through a 150-mile radius area centered near Nassau, Bahamas, accessed through the NOAA Digital Coast tool (NOAA, 2019).

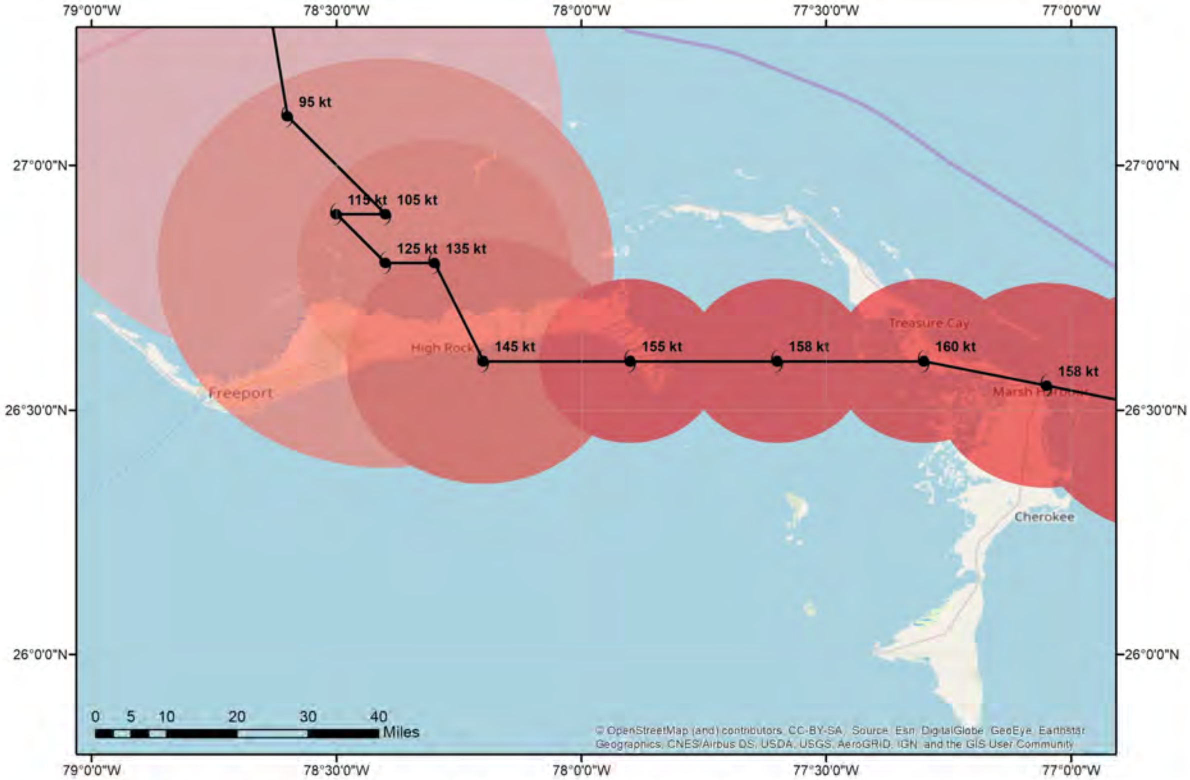
2.0 Hazard Characteristics

The following sections summarize the hazard characteristics for Hurricane Dorian, focusing on the Bahamas, introducing new information beyond what was reported in the StEER Preliminary Virtual Reconnaissance Report (Kijewski-Correa et al., 2019).

2.1 Meteorological Background

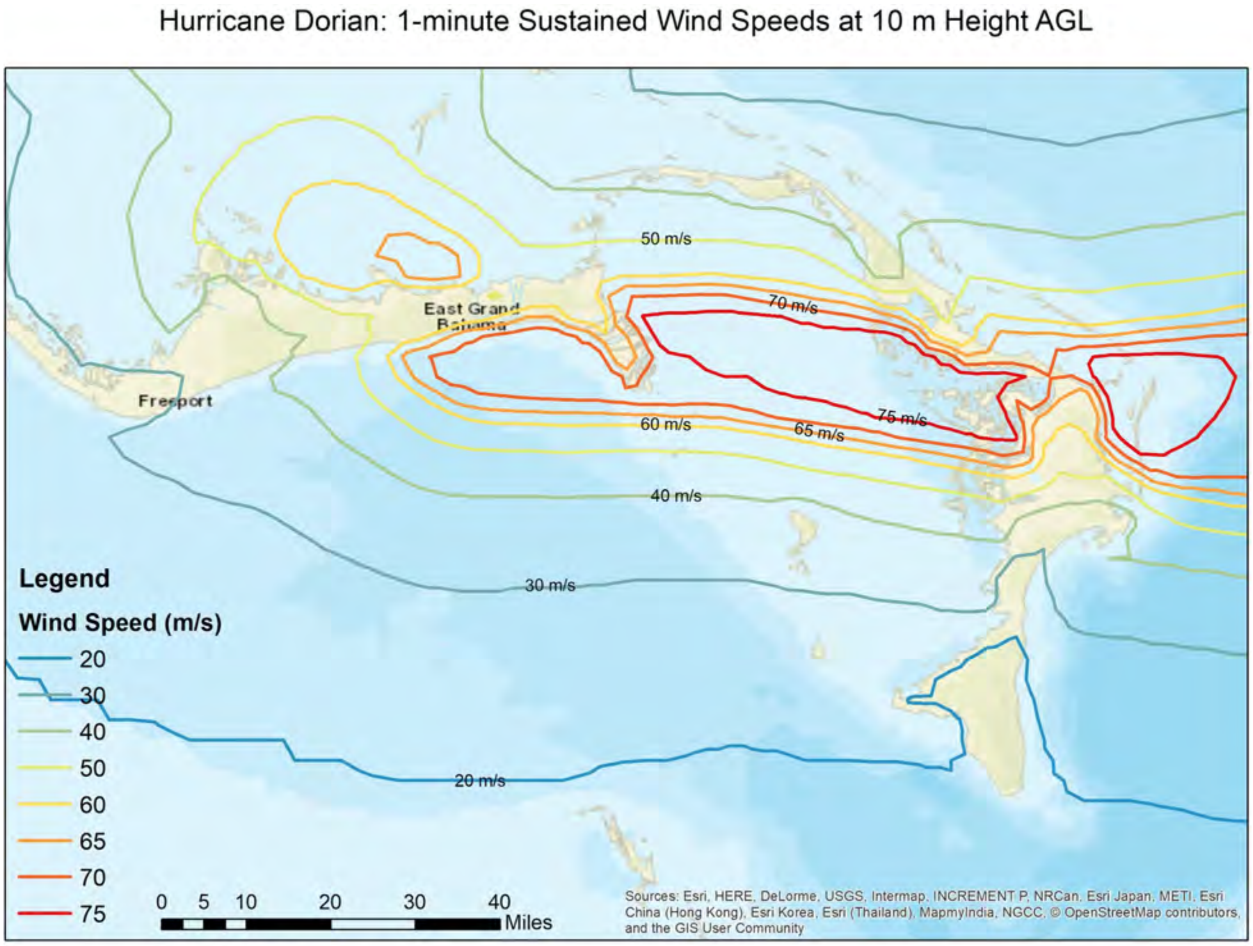
A description of the complete track for Hurricane Dorian, including landfalls in the Bahamas and the US, are provided in Kijewski-Correa et al. (2019). Dorian began on August 24, 2019 as Tropical Depression 5 in the South Caribbean, about 140 miles north of Brazil. It was first classified as a hurricane on August 28, 2019 near St. Thomas. Dorian strengthened to a Category 5 hurricane on the Saffir-Simpson scale as it passed through the Bahamas, where it stalled for about nearly 30 hours, then weakened to a Category 2, and eventually to a Category 1 hurricane as it moved up the east coast of the United States, staying just offshore. Dorian ultimately made landfall again in Nova Scotia, Canada as an extratropical system with wind speeds equivalent to a Category 1 hurricane.

Figure 2.1 summarizes the intensity of Dorian as it passed through the Bahamas. Maximum sustained wind speeds were near 160 knots (82 m/s) when it made landfall in Elbow Cay and Marsh Harbor on Great Abaco. The radius of maximum wind speeds at landfall was 10 nautical miles, placing Treasure Cay in the right eyewall. Dorian maintained its intensity as it moved west towards Grand Bahama, making landfall in the largely undeveloped southeast end of the island with maximum sustained wind speeds estimated at 155 knots (80 m/s). Dorian continued west before making another landfall near High Rock in the Grand Bahamas with sustained wind speeds of 145 knots (75 m/s) and a radius to maximum wind speeds of 15 nautical miles, which did not reach the more populated regions in Freeport. After crossing Grand Bahama, Dorian nearly stalled just north of the island while it's intensity dropped and the eyewall expanded. The expanding eyewall ultimately reached Freeport, but not until sustained wind speeds had fallen to 125 knots.



Extent of the radius to maximum wind speed and the corresponding maximum sustained wind speed for Hurricane Dorian. Data sourced from forecast advisories provided by the National Hurricane Center. Some values shown are interpolations to improve coverage. Map created by David Roueche (Auburn University).

Figure 2.1. Track of Hurricane Dorian through Grand Bahamas and the Abacos Islands with estimated maximum sustained wind speeds as provided in the NHC forecast advisories. Polygons indicate the radius to maximum wind speeds, also based on the NHC advisories. All areas within the polygon would not necessarily have experienced the maximum sustained wind speeds (1 knot = 1.15 mph = 1.85 km/h).



Hurricane Dorian: 1-minute Sustained Wind Speeds at 10 m Height AGL

Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

Wind speeds estimated using NHC data for Hurricane Dorian, including RMW, minimum central pressure, and maximum sustained wind speed estimates. The wind field was developed by James Done at the University Corporation for Atmospheric Research based on the modeling approach described in the following paper:

Done, J. M., Ge, M., Holland, G. J., Dima-West, I., Phibbs, S., Saville, G. R., and Wang, Y.: Modelling Global Tropical Cyclone Wind Footprints, Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2019-207, in review, 2019.

Figure 2.2. Maximum 1-min sustained wind speed at 10-m height adjusted for local terrain. Wind field analysis conducted by James Done at the University Corporation for Atmospheric Research (UCAR) (1 m/s = 1.94 knots = 2.24 mph = 3.6 km/h).

2.2 Wind Speed Observations Near Grand Bahama and Abaco Islands

Limited surface wind observations are available for Dorian in the Bahamas as most instrumentation in the path failed or stopped reporting. An anemometer at Settlement Point, on the far west end of Grand Bahama, reported a peak gust of 78 mph (Datascope, 2019), but was located 38 miles (~ 1.5 RMW) from the center of Dorian when the maximum sustained wind speeds were near 145 mph. No other observations near impacted areas of the Bahamas are available. The wind field analysis in Figure 2.2 does provide some indication of the distribution of maximum sustained wind speeds in the event.

2.3 Storm Surge

Storm surge was estimated to be as high as 23 ft above mean sea level as Dorian made landfall in the Abaco Islands, with the highest water heights occurring in Marsh Harbour and the eastern cays (Man-o-War, Elbow). In Treasure Cay, the Coastal Emergency Risk Assessment (CERA) tool estimated maximum water heights up to around 12 ft above the mean sea level (Fig. 2.3). In Grand Bahama, the highest storm surge was estimated to be along the northern coastline (see Fig. 2.3), with CERA estimating maximum water heights around 16 ft above mean sea level (CERA, 2019).

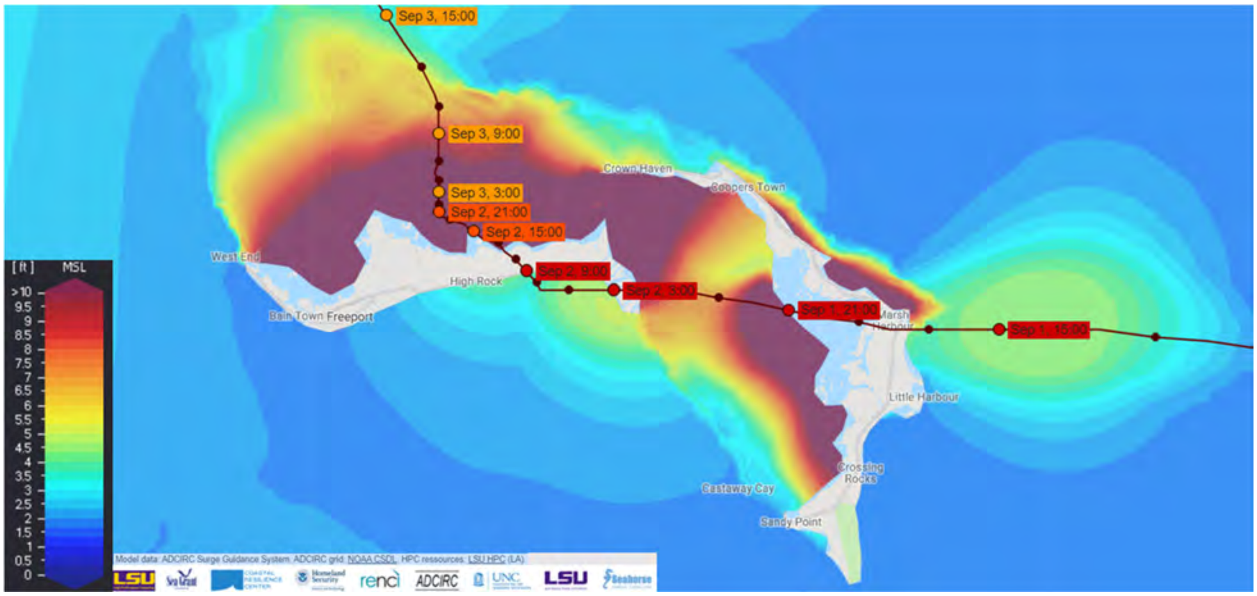


Figure 2.3. Maximum water heights surrounding the Abaco Islands and Grand Bahama due to Hurricane Dorian, as estimated by the Coastal Emergency Risk Assessment platform.

3.0 StEER Response Strategy

StEER Activated its FAST-1 relatively swiftly based on a target of opportunity made possible by Steve Pece, of Pece of Mind Environmental, Inc., who offered unique access using personal resources and connections. The team departed Florida on the morning of September 24, 2019 and was led by Justin Marshall of Auburn University, who was flanked in structural damage assessments by Daniel Smith of the Cyclone Testing Station/NCAR/University of Florida. Andrew Lyda, Operations Engineer with the RAPID EF at the University of Washington, joined the mission as an imaging specialist rapidly gathering imagery using Applied StreetView technologies. The team collected data in Great Abaco on September 24 and 25 (departing on September 26), focusing on Marsh Harbour and Treasure Cay. While the FAST-1 response was partially limited due to the logistical challenges of arriving that soon after landfall and minimizing the time on the ground given the ongoing recovery work. Even so, FAST-1 was able to rapidly generate a rich dataset by leveraging a diverse suite of technologies, including:

- DJI Osmos, Insta360 camera

- Applied StreetView (AS camera)
- Door-to-door (D2D) assessments using customized assessment forms deployed via the Fulcrum mobile app and data collection platform

Attention was centered on these two regions since they: (i) experienced the highest magnitudes of wind and storm surge, (ii) contained diverse building and other structure typologies, and (iii) had sufficient building/population density to generate a collection of robust sample sets over compact areas. Post-Dorian satellite imagery obtained by StEER was also used pre-deployment to identify a number of apparent "successes" in these regions, some of which were highlighted in the PVRR (Kijewski-Correa et al., 2019). Such success can provide the greatest learning potential related to structural performance of buildings and other structures.

The StEER response strategy centered on pre-identifying clusters of structures based on typology, year of construction, post-Dorian performance (as indicated by satellite imagery), and hazard intensity. Both Marsh Harbour and Treasure Cay were within the eyewall of Dorian, suggesting that the wind speed gradient would not be substantially different between the two regions. However, storm surge and wave action still varied substantially across these regions depending on distance inland and local topography. FAST-1 documented performance under a variety of storm surge heights based on initial eyewitness reports. The second StEER FAST (FAST-2) then focused on more accurate assessments of storm surge hazard characteristics.

For the clusters of structures that were identified and assessed, the StEER FAST-1 conducted D2D assessments at regular intervals (e.g., every third structure) within each cluster to avoid biasing. The D2D assessments were supplemented by the AS camera, which was able to cover larger areas for rapid assessment of surrounding damage.

It is important to note that detailed forensic investigations were generally not achievable within the scope and time limits of FAST-1. Instead, focus was provided on broadly assessing building performance over populated regions within the impacted area and over a wide range of structural typologies. 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. Such follow-on investigations are certainly warranted to examine the performance of specific typologies or regions within the Bahamas, as further discussed in Section 9.

4.0 Local Codes and Construction Practices

Construction in the Bahamas is regulated by the 2003 Bahamas Building Code (BBC), which references the wind design provisions of the 1988 edition of ASCE 7.[1] As described in the PVRR (Kijewski-Correa et al., 2019), initial reports suggest that the areas most impacted by Dorian consisted largely of a mixture of low-rise residential and rental properties, light industrial

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[1] https://www.bahamas.gov.bs/wps/wcm/connect/d7ebcbad-f9b6-42e3-aff2-79f83bd91810/Bahamas%2BBuilding%2BCode%2B3rd%2BEd.pdf?MOD=AJPERES

development, and commercial development. In some localities, construction is subject to additional architectural constraints. In low-income neighborhoods and informal settlements, there is no guarantee that residential construction has been built in accordance with the 2003 BBC.

Residential construction practices varied somewhat from what would be expected in typical Florida construction. The most standard construction method for homes is unreinforced masonry weakly confined with vertical concrete elements (reinforced with four #4 longitudinal bars) spaced approximately 10 feet on center and bounded by a lightly reinforced concrete ring beam. Most roofs are wood-framed trusses fabricated on site. FAST-1 documented a number of these trusses with wood panel plated connections between truss elements. FAST-1 further observed that ties/hurricane straps were standard practice (not having them is the exception), although the type and number of fasteners used in the straps often did not meet manufacturer specifications.

Two somewhat unique roof cover systems were observed in both single-family and commercial residential buildings. One is a marine grade ¾" overlapped plywood sheets (producing a look similar to flat profile roofing tiles) and covered with a waterproofing compound. The other is an insulated styrofoam roof system with a thin hardiboard veneer. Secondary water barriers (primarily self-adhered membranes) were observed in a few instances, but it was unclear whether their use designated common practice.

5.0 Reconnaissance Methodology

5.1 Door to Door (D2D) Assessments

D2D Damage Assessments were recorded using a Fulcrum mobile smartphone application acquiring geotagged photos, recorded audio and other relevant metadata from the investigator's mobile device. Prior to deployment, the Fulcrum app was populated with customized layers containing post-Dorian high-resolution satellite imagery, pre-identified clusters of target structures, and standard basemaps for use offline while in the field with limited connectivity.

The FAST-1 emphasis was placed on documenting the structural performance of as many structures as possible in a short amount of time, while capturing the minimal depth of information needed for a useful assessment, supplemented by more in-depth case study assessments where warranted. A typical assessment included: 1) collecting clear photographs from multiple perspectives, 2) accurately geo-locating the assessments over the target building or structure, 3) filling out site-specific fields which require on-site forensic investigation and structural engineering expertise, and 4) noting unique features of structures that would affect windstorm performance and not be otherwise visible from supplemental data sources. Figure 5.1 plots the location and overall damage status of each assessment in Marsh Harbour and Treasure Cay, overlaid on post-event satellite imagery. In total, FAST-1 logged 97 individual assessments, with observations documented via pre-defined app fields, supplementary notes, geo-tagged photographs, and audio recordings. Fulcrum data can be accessed immediately at StEER's Fulcrum Community page.

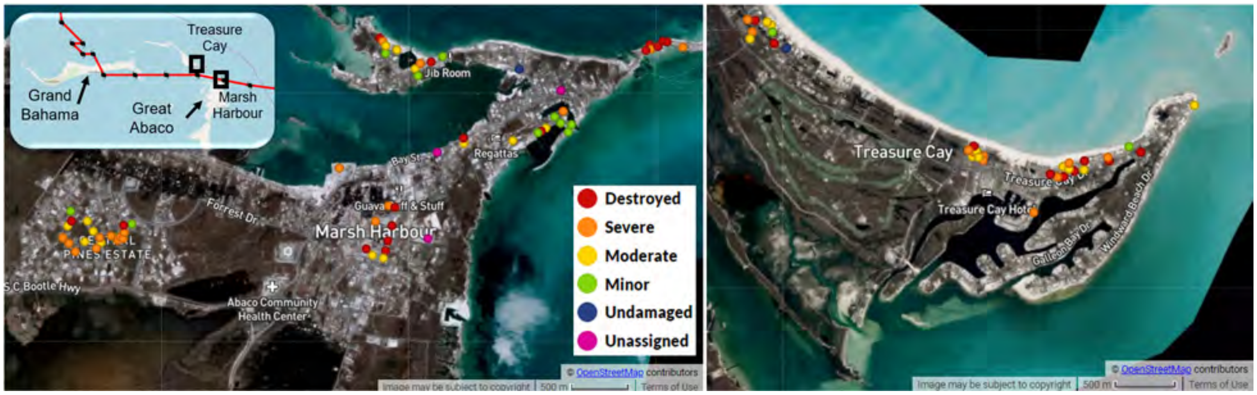

Figure 5.1. D2D assessments by FAST-1 in Marsh Harbour (left) and Treasure Cay (right).

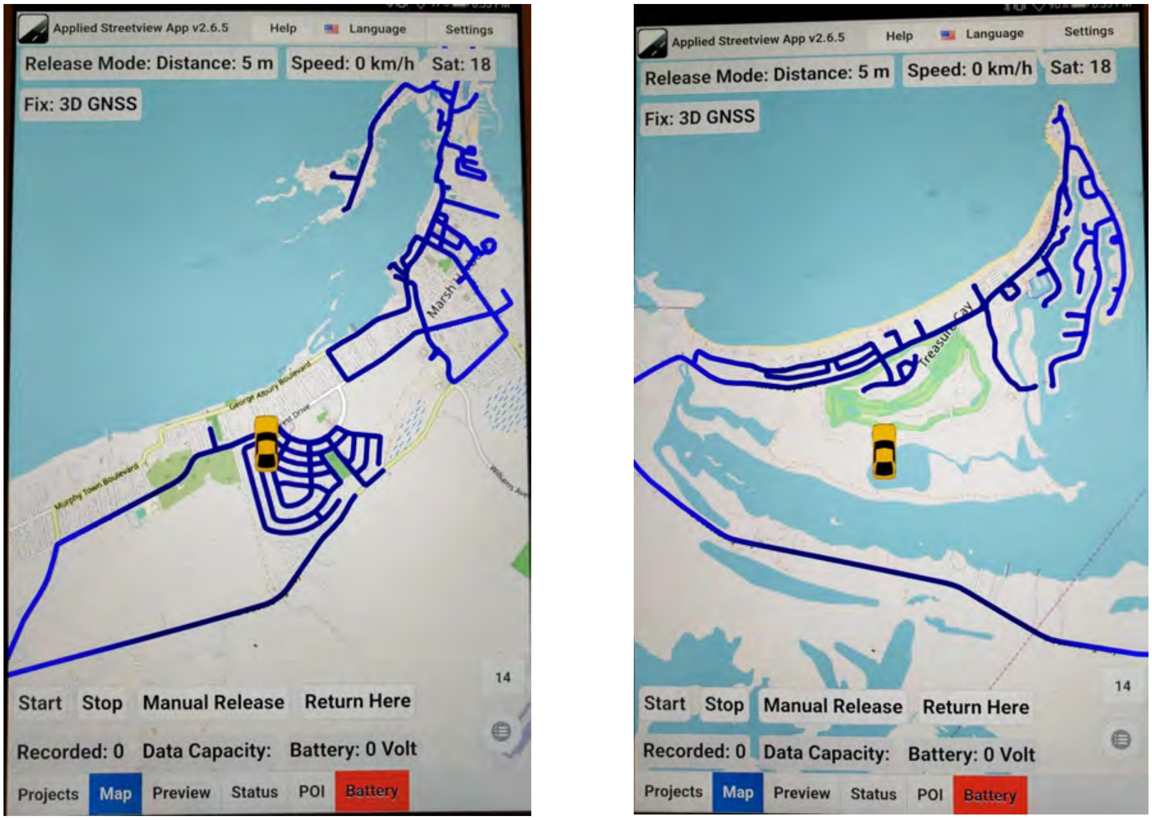

Figure 5.2. StreetView routes through Marsh Harbour (left) and Treasure Cay (right).

5.3 Applied StreetView Imaging

Figure 5.2 visualizes the routes captured by the Applied StreetView system in Marsh Harbour and Treasure Cay. Using the GPS-tracking, and 360 degree panoramic photographs taken at 5 m intervals by the Applied StreetView system, the FAST-1 captured near-continuous coverage of exterior building performance along the routes driven. The data has been processed and is currently available through the UW NHERI RAPID facility.

6.0 Observed Performance of Buildings

Marsh Harbour and Treasure Cay were both heavily damaged by Dorian. FAST-1 documented a range of structural performances in both, from destruction to no/minor visible damage, across a mix of building typologies that included single- and multi-family residential, commercial, and institutional buildings. A high-level summary of these assessments is cataloged in Appendices A and B, respectively. From preliminary observations of FAST-1 and analysis of post-Dorian satellite imagery, the dominant factors impacting the high variance of performance appear to be: (1) proximity to the coastline, as wave action enhanced damage caused by surge and high winds; (2) building typology; and (3) year built, most likely representing enhanced construction techniques in newer buildings, but potentially including effects related to the degradation of materials in older buildings due to the location in a corrosive coastal environment. Wind speed was obviously a dominant factor in damage experienced overall, but a strong wind speed gradient, as indicated previously in Figure 2.1, was not apparent. There also did not appear to be significant differences in construction styles between Marsh Harbour and Treasure Cay. For this reason, the observations from the FAST-1 are organized in the following sections by hazards present, and secondarily by building typology.

6.1 Damage under Wind, Wave and Surge Action

Buildings along the east coast of Great Abaco between Marsh Harbour and Great Abaco experienced the worst of high winds, waves, and storm surge from Hurricane Dorian, with FAST-1 observing high water marks up to 20 ft above the mean water line. The buildings assessed by the FAST-1 that were located near the eastern coastline included residential and commercial buildings along East Bay Street, and mostly residential buildings along Eastern Shores Road and Pelican Shores Drive. Buildings near the eastern shore in Treasure Cay may have experienced significant wave action, but the FAST-1 observed that wave action there appeared to be less dominant than in Marsh Harbour.

6.1.1 Residential Buildings

The variation of damage to residential buildings in these areas ranged from total destruction up to the exterior of the building being essentially undamaged. For example, Figure 6.1 contrasts two homes located along Pelican Shores Drive. One home (left) appeared undamaged by Dorian, although significant interior damage due to water infiltration from surge did occur, located on the eastern coast (green dot on the inset map), while the other home (right) was completely destroyed (red dot on the inset map). The home on the left was constructed in 2007 out of concrete masonry, with hurricane shutters over openings and a hipped metal roof, while the home on the right pre-dates 2005 (exact date of construction unknown) and details of its structural load path were not discernible in the debris.

Figure 6.1. Contrast between the performance of two homes located along Pelican Shores Drive exposed to the worst of Dorian’s wind, storm surge and waves. The home on the left is located at [26.552164, -77.055065], and the home on the right at [26.551852, -77.055599].

Along Pelican Shores there were a number of homes that were elevated above grade using lightly reinforced concrete columns while others were elevated on masonry walls 3 to 4 ft above grade; still others were slab on grade. The significant wind and surge essentially completely demolished several of these homes. The small cottages that were constructed with slab on grade foundations as indicated in Figure 6.2a by orange markers, had only their foundations remaining. Other structures, marked by red markers, which were elevated at heights from 4 ft up to approximately 8 to 10 ft on concrete columns, were also washed away. Some noteworthy structural observations:

1. the amount of reinforcing steel in the concrete columns was very low (four #4 or #5 longitudinal bars for a 12”-16” diameter column)
2. the foundation and anchorage was insufficient to resist lateral forces
3. only a single anchor bolt attached the structure to the column.

Figure 6.2b and 6.2c show examples of these columns in their final position.

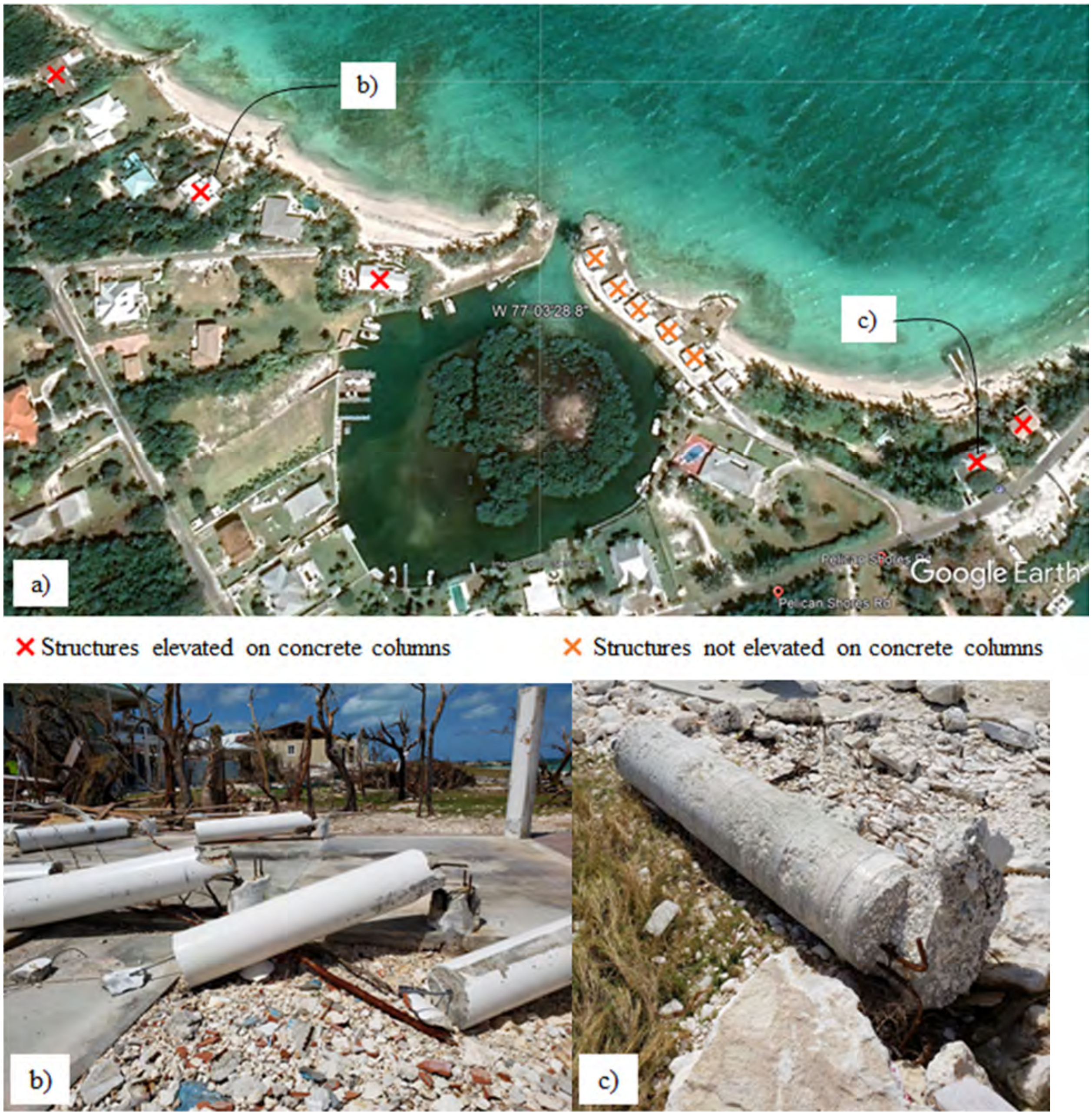

Figure 6.2. (a) Google Earth map indicating structures that collapsed due to wind and surge along the coast. The structure on the far left with a red marker is located at [26.55363, -77.06072]. (b) Toppled concrete columns showing minimal corroded reinforcement and a single anchor bolt to attach to the supported structure located at [26.44297, -77.05980]. (c) Toppled concrete column showing minimal reinforcing and anchorage into a footing located at [26.55174, -77.05588].

Homes along Eastern Shores Road generally appeared to belong to more affluent households, but the damage that was accessible to the FAST-1 was some of the worst observed in Great Abaco. Due to road washout, the team was not able to extend assessments along the full length of the road, but where they were able to assess, all buildings were at least severely damaged if not completely destroyed. As shown in the PVRR (Kijewski-Correa et al. 2019), there were some homes in the far eastern portions that did perform well based on exterior views. Figure 6.3 shows a sample of typical single-family residential performance along the accessible portions of Eastern Shores Road. Some of the structures that were totally destroyed but were constructed with concrete had very light to no reinforcing and minimal connection between the elevated structure and the concrete podium structure below.

Location: 26.553245, -77.035057 Location: 26.552954, -77.035934

Location: 26.552642, -77.036987 Location: 26.552890, -77.033697

Figure 6.3. Typical performance of single-family residences along Eastern Shores Drive.

6.1.2. Commercial Buildings

Commercial buildings along the eastern shore of Marsh Harbour (mostly along Bay Street) exposed to high winds, waves and storm surge did not fare well, with most completely destroyed. Figure 6.4 shows the Harbour View Marina, which was completely destroyed. The marina was only reinforced at approximately 7 ft on center, with unreinforced and ungrouted cells in between.

FAST-1 also investigated buildings in the International Port Area, including what appeared to be the main receiving warehouse, a metal building with steel moment frames, X-bracing, unreinforced masonry block in-fill walls and a standing seam metal roof (Fig. 6.5). The building was gutted by the hurricane, with only the structural frame remaining, albeit partially collapsed on the coastward side of the building (north-facing). The building pre-dates 2005 imagery but exact year of construction is unknown. Surface corrosion was visible during the on-site inspection, but it is unlikely that it was a significant performance factor.

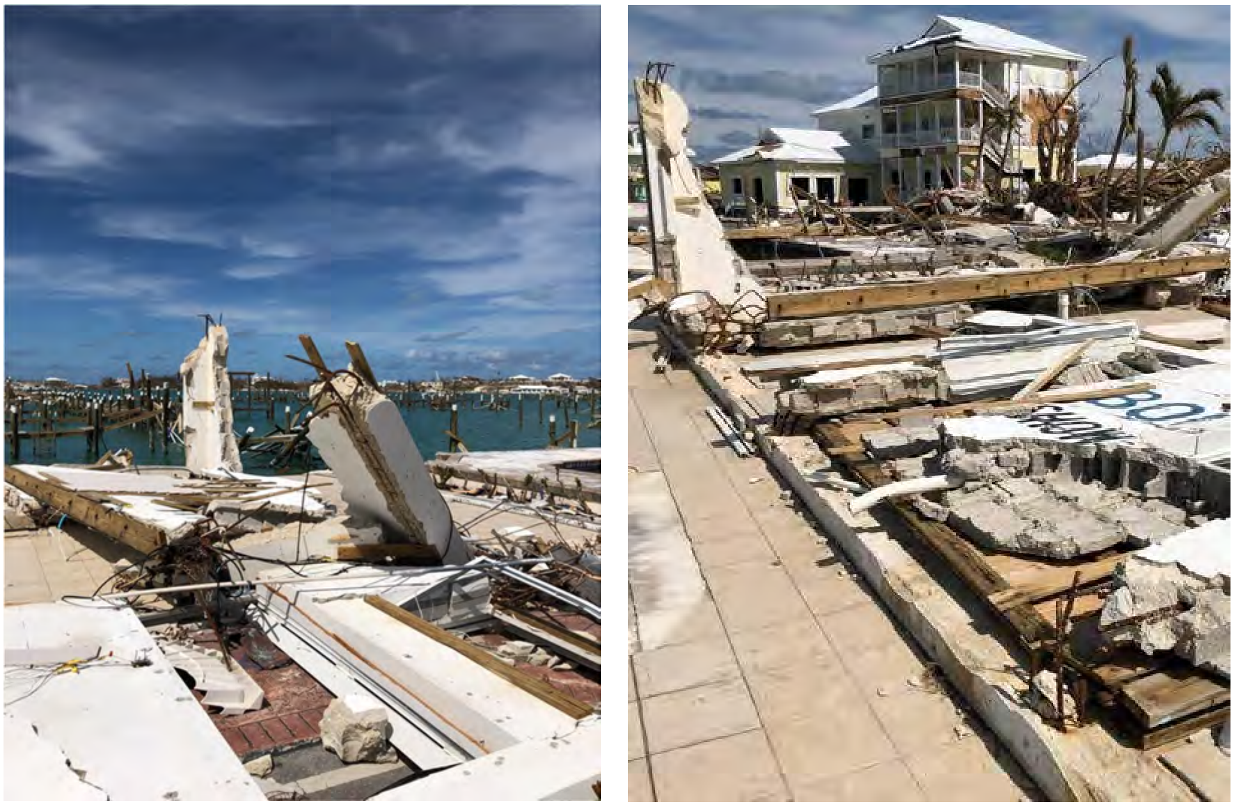

Figure 6.4. Destroyed marina in Marsh Harbour constructed with masonry block, unreinforced between grouted, reinforced columns located approximately 7 ft on center.

Figure 6.5. Metal building at the International Port Area destroyed by high winds, waves and storm surge.

6.2 Damage under Wind and Surge Action

This section describes damage to buildings, which appeared to be driven primarily by wind and storm surge, with less evidence of significant damaging wave action. Regions included in this section are the Abaco Resort, majority of Treasure Cay, and the industrial region of Marsh Harbour. Overall, damage still varied between complete destruction to no/minor damage. Destroyed buildings in these areas generally remained collapsed in place rather than being washed away.

6.2.1 Residential Buildings

A variety of damage modes were observed in residential buildings. Destroyed homes typically experienced the loss of the roof structure (e.g., Fig. 6.6 (left)) and sometimes also the elevated wood-frame structure, although at least one wood-frame home experienced a failure mode akin to soft story collapse, apparently due to storm surge (Fig. 6.6 (right)). A number of wall-to-foundation failures were noted, despite the presence of anchor bolts, as illustrated in Figure 6.7. FAST-1 observed only isolated instances, if used at all, of metal straps connecting wood stud walls to sill plates, which would have left a critical weak link in the structural load path.

As noted elsewhere, there were a number of residential buildings that performed well structurally, although surge and rainwater ingress likely compromised interiors. Figure 6.8 shows a collection of such well-performing single-family homes in regions subjected to high wind and surge. Note the single story masonry block home (unknown reinforcement) with a hip/gable roof, windows protected by plywood panels, and an asphalt shingle roof that performed reasonably well structurally (Fig. 6.8a). A high water mark here was measured at ~6 ft above ground level. While many of these homes were higher-end construction, at least one, shown in Figure 6.8c, appeared to be a more modest older home, yet survived with just 1.5 roof sheathing panels removed and approximately 40% roof cover loss. The interior damage in this case may result in a total loss, but given the wind speed estimates, and the older style of construction, the lack of structural damage provides an interesting case study. Unfortunately, the FAST-1 was not able to access the interior of the home to assess the structural load path.

Figure 6.6. Severe damage to residential buildings, including loss of roof over top story (left) and collapse of bottom story in wood-frame building (right).

Figure 6.7. Typical connections of elevated wood-frame construction atop reinforced masonry ground floor construction. Anchor bolts were commonly observed anchoring the sill plates (shown above) but in failed buildings, straps were not utilized to provide a strong positive connection between the studs and the sill plate.

(a) Location: 26.686085, -77.302603

(b) Location: 26.677877, -77.270224

(c) Location: 26.546759, -77.043610

(d) Location: 26.547378, -77.045113

Figure 6.8. Sampling of performance under wind and storm surge across residential construction at various tiers of property value.

6.2.2. Commercial Buildings

The primary commercial district in Abaco is along Don Mackay Boulevard, which is generally south of the Marsh Harbor Government Port. FAST-1 assessed 10 buildings in the region. The breakdown of damage statistics for this region is shown in Table 6.1. This region was affected by both wind and surge but was far enough inland that the wave action would not have been significant. It was clear from several buildings and boats displaced from the marina that water ingress and flooding occurred. While a clear waterline indication was not found in any of the buildings, FAST-1 estimated that flooding was likely in excess of 5 ft above grade. The one building that was classified with “minor” damage was Maxwell’s grocery store (Fig. 6.9a), which is the main supermarket for Marsh Harbour. It was not operational but the damage was primarily to the building envelope. The solar panels on the roof survived the high winds and according to reports were undamaged. Figure 6.9b shows a metal building (Ace Hardware) that was classified with “moderate” damage, primarily loss of building envelope, which resulted in significant damage due to water ingress. Figure 6.9c shows a gas station that was classified as destroyed. It is apparent in the photo that the surge caused one of the refrigerators to float from its original position.

Table 6.1. D2D damage ratings of commercial buildings assessed in Marsh Harbour

Damage State	Number of Structures
Undamaged	0
Minor	1
Moderate	2
Severe	3
Destroyed	5

6.3. Damage under Wind Action only

The Central Pines residential area is a neighborhood that is about 15 years old, located to the east of downtown Marsh Harbour and adjacent to Abaco Primary School [26.54014, -77.07988]. Based on discussions with local residents, most of the houses (about 75% in their estimation) have been built in the last 10 years. The most common construction method in the neighborhood consists of lightly confined, unreinforced masonry walls (vertical confining elements only at the corners and around windows/doors) with a wood-framed hipped or gabled roof. There were also a few timber framed residences (less common). All of the residences in this region are either one or two-story structures. This was a region that was not affected by flooding or storm surge. This was due to a low-lying area to the north of the neighborhood along Forrest Drive, which was inundated during the storm but prevented flooding in Central Pines. Thus this neighborhood provides a unique perspective of homes that were damaged only by Hurricane Dorian's high winds. Figure 6.10 shows the D2D breakdown of the 20 different residences that were assessed by FAST-1. The distribution of damage states is shown in Table 6.2. It is clear that due to Dorian's high winds, even without surge and flood effects, was sufficient to severely damage or destroy more than of the homes.

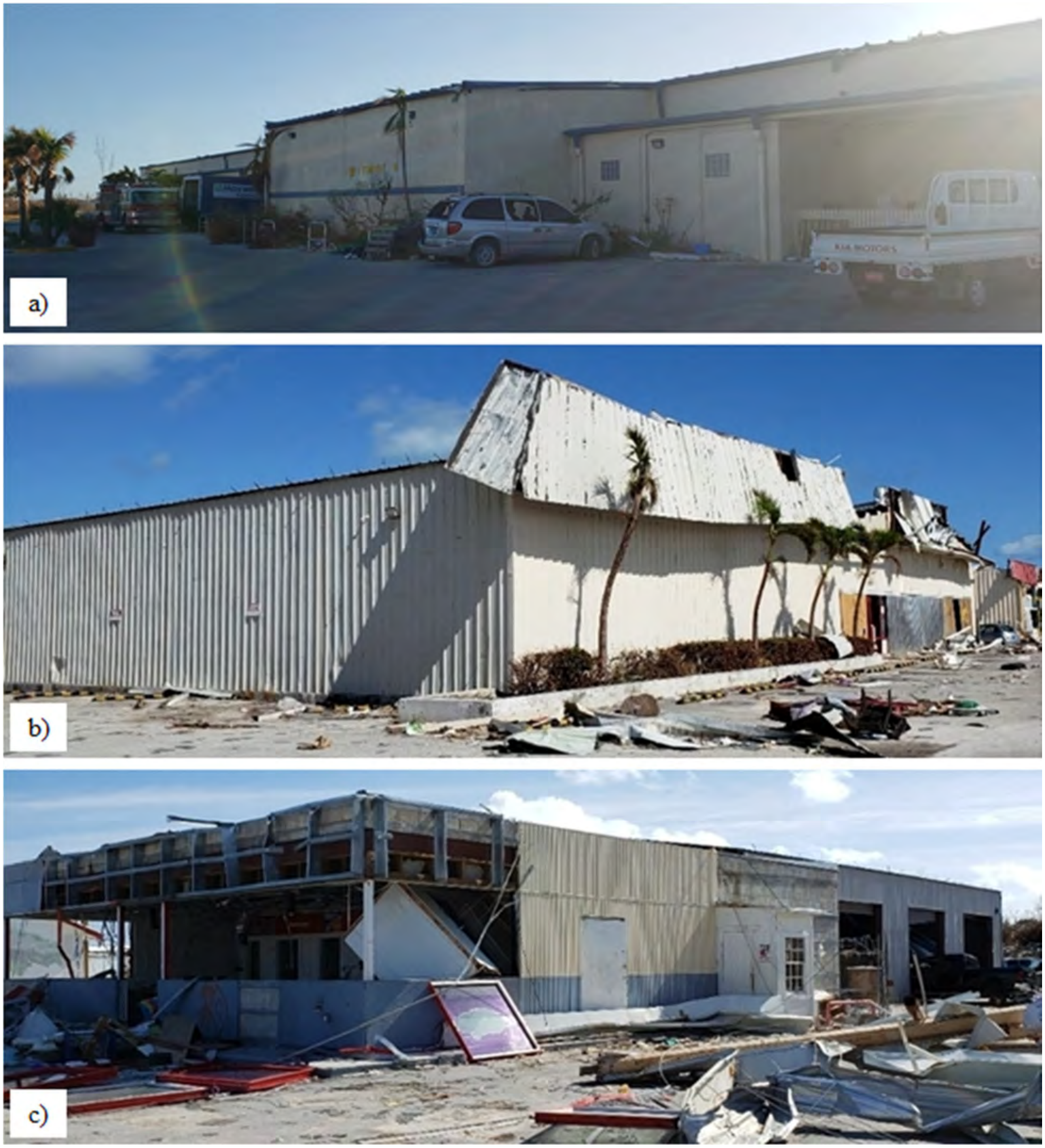

Figure 6.9. Variation of damage to commercial buildings in Marsh Harbour: (a) Minor damage to Maxwell's grocery store [26.53773, -77.05638]; (b) Moderate damage to Ace Hardware (metal building) which also showed significant water ingress damage [26.536398, -77.06132]; (c) Destroyed gas station with evidence of significant flooding due to the refrigerator that has been lifted and moved [26.53677, -7706014]

Table 6.2. D2D wind damage ratings from Central Pines residential neighborhood

Damage State	Number of Structures
Undamaged	0
Minor	3
Moderate	6
Severe	9
Destroyed	2

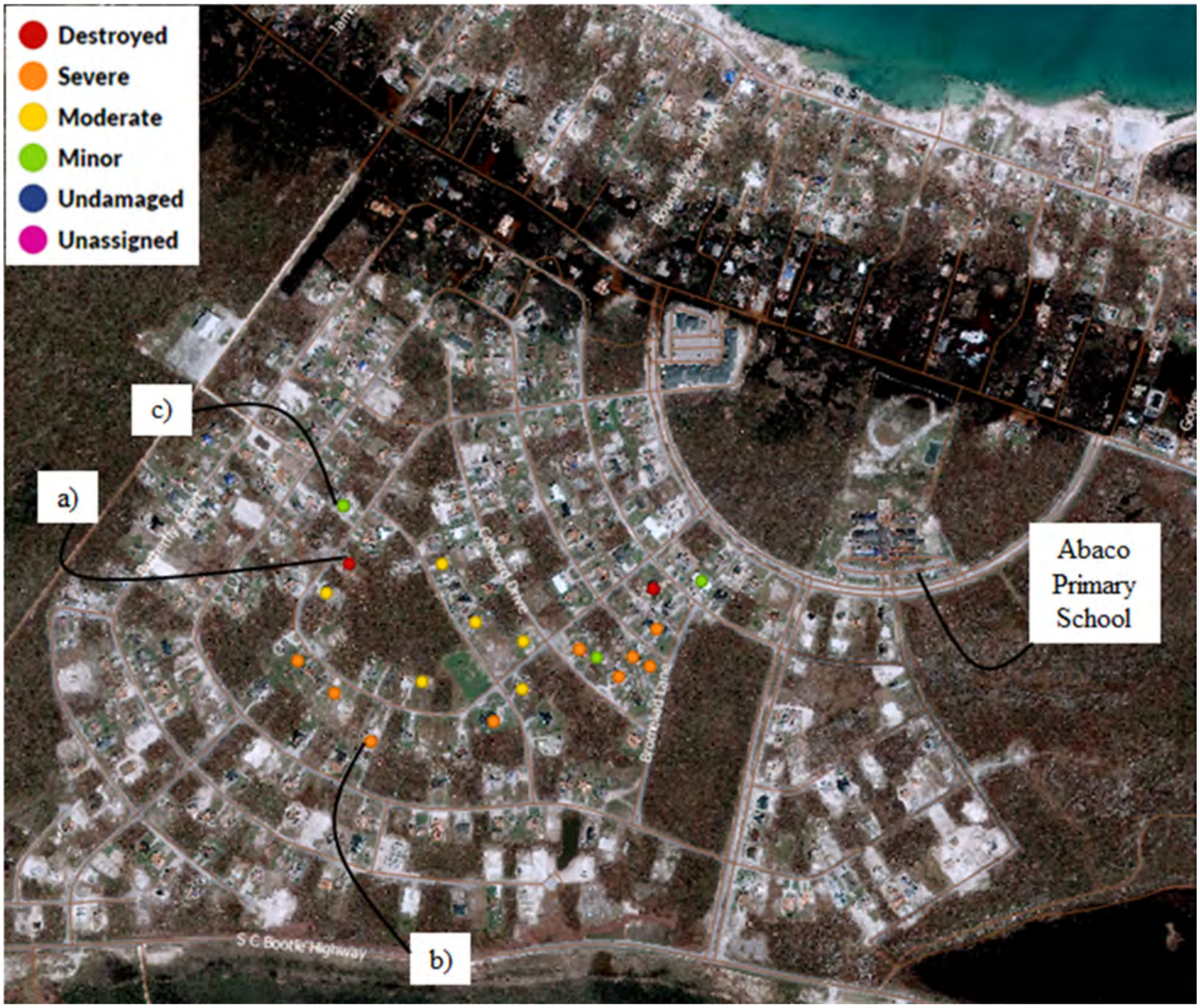

Figure 6.10. Fulcrum damage assessments in Central Pines residential neighborhood. Note that letters indicated in map reference photos in Figure 6.11.

Figure 6.11 shows examples of the variation in damage states in the Central Pines neighborhood. Figure 6.11a shows a "Destroyed" wood-frame home that was built between 2007 and 2012. Figure 6.11b shows a home that was built around 2005 with severe damage due to a partial loss of the roof structure over the two-story portion of the home. Figure 6.11c shows a residence that experienced only minor damage. This was the newest of the three structures based on historical imagery that suggests it was constructed in 2018.

Figure 6.11. (a) Example of "Destroyed" wood-frame residence in Central Pines [26.53908, -77.08815]; (b) Example of "Severe" damage in Central Pines [26.53713,-77.08815]; (c) Example of "Minor" damage in Central Pines [26.63991, -77.08816].

7.0 Observed Performance of Infrastructure

7.1 Power and Telecommunications Infrastructure

Limited cell service was available on the island during the FAST-1 deployment, but without a reliable data connection. Power was not available due to damage to the power lines and poles. Great Abaco relied upon a network of power poles and distribution lines that was heavily damaged by Dorian with most power poles in Marsh Harbour snapped or collapsed (Fig. 7.1). In Treasure Cay, many power poles were downed, but it was more common to see intact poles and distribution lines, especially along the main highway (Treasure Cay Drive). In addition, the Marsh Harbour power station [26.53466, -77.09566] was severely damaged by Dorian's winds. While the team did not do any assessments of the power plant buildings, the damage, primarily to the cladding elements, is clearly visible in the StreetView imagery in Figure 7.2 and from high-resolution satellite imagery.

Figure 7.1. Snapped and leaning power poles in the business district of Marsh Harbour captured by the NHERI RAPID EF Applied StreetView camera.

Figure 7.2. Applied StreetView image of damaged Marsh Harbour power plant facility [26.53466, -77.09566].

7.2 Airports

There are three airports on Great Abaco Island (Leonard Thompson International, Treasure Cay and Sandy Point). Only the Leonard Thompson airport was visited by the team and it was not assessed in detail. Two of the buildings in the private charter portion of the airport were assessed in Fulcrum. One was the Flight Base Operations Jet Center, which is a single story professional building built similar to a typical residential building (Fig. 7.3a). This building was essentially undamaged and was in operation for all the private flights coming in and out of the airport. The other assessed building was the hangar for Cherokee Aviation, which was a metal building (Figure 7.3b). This building was assessed as severely damaged, with partial collapse of the end bay.

7.3 Roadways

Several examples of damage to roadways were observed due to the surge effects of Hurricane Dorian. Within Marsh Harbour, the damage was primarily evident in Pelican Shore and Eastern Shore, with the two most significant examples on Eastern Shore. The first location was a complete washout of the roadway, which prevented access to Eastern Shores (small pedestrian walkway was erected to allow for some access of personnel) (Fig. 7.4a). Not much further down the road from the complete washout was a section of the roadway with concrete pavement and a partial concrete guardrail that was significantly damaged by the effects of surge (Fig. 7.4b). This was the region of Marsh Harbour where some of the highest surge levels were reported.

Figure 7.3. Examples of structures assessed by the D2D team at the Leonard Thompson International Airport: (a) Flight Base of Operations (FBO) Jet Center, assessed as “Undamaged” [26.51362, -77.08426]; (b) Cherokee Aviation hangar building, assessed as “Severe” damage [26.51353,-77.08483].

Figure 7.4. Examples of roadway surge damage: (a) Complete roadway washout of Eastern Shores road which has been temporarily replaced with a pedestrian bridge [26.55190, -77.03761]; (b) Roadway erosion of concrete pavement and guardrail on Eastern Shores Road [26.55313,-77.03569].

Another example of significant damage was the road to Treasure Cay from Marsh Harbour. This section of the roadway was recently reconstructed with a number of concrete culverts due to the fact that this was a low-lying thoroughfare adjacent to a small waterway. The location of the roadway is on the western side of the island, indicating that in this area the surge was moving from the eastern coast along this waterway to the western side of the island. The damage from the StreetView camera is evident in Figure 7.5.

Figure 7.5. StreetView image of damage to a recently reconstructed roadway on the road from Marsh Harbour to Treasure Cay [26.58216, -77.16946].

7.4 Port Facilities

The Marsh Harbour Government Port [26.54276, -77.06433] was operational during the time FAST-1 was on the ground. It was serving as a water and food distribution point although these operations were moved to Abaco Primary School during the time the team was on the ground. The team assessed only one of the buildings, a metal building that was used for storage and was classified as “Severe” damage. Figure 7.6 shows the warehouse building that was damaged by Hurricane Dorian and would have experienced both high winds and surge. StreetView imaging captured the current status of the port as well. Figure 7.7 shows some of the temporary facilities supporting aid operations at the port, with a view of the destroyed administration building visible in the background.

Figure 7.6. Image of damage to warehouse building at Marsh Harbour Government Port [26.54332, -77.06435].

Figure 7.7. StreetView imagery of the temporary structures set up at the port facility, with view of the destroyed Administration building in the background.

8.0 Observed Evidence of Hazard Intensity

8.1 Wind Hazard Intensity

A number of snapped power poles and light posts were observed by the D2D team and are documented in the previous StreetView images in Figure 7.1. A detailed analysis has not been conducted to date, but the data could be used to assess the relative hazard intensity across the impacted regions in Marsh Harbour and Treasure Cay.

8.2 Storm Surge Intensity

FAST-1 documented high water marks relative to ground elevation where available in a number of locations throughout Marsh Harbour and Treasure Cay. A summary of these observations is provided in Figure 8.1. FAST-2 will conduct a more rigorous assessment of surge inundation in both the Abaco Islands, Grand Bahama and neighboring cays as time and weather permit (see Section 9.0).

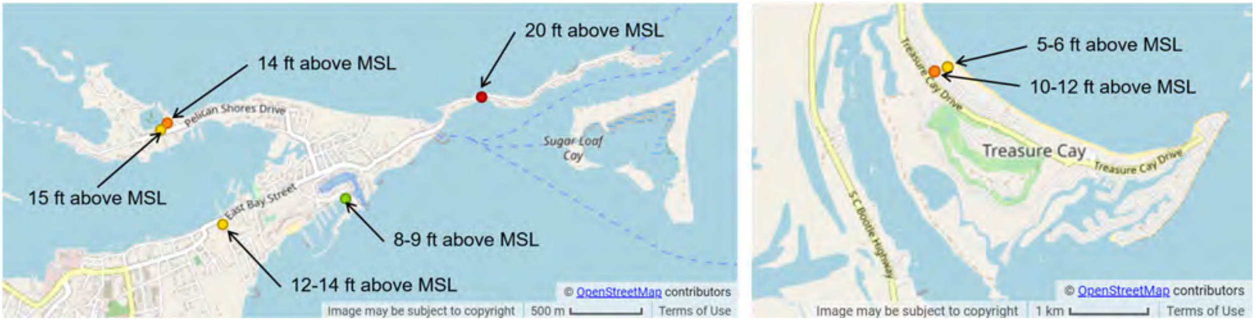

Figure 8.1. Surge height estimates documented by FAST-1 for (left) Marsh Harbour and (right) Treasure Cay.

9.0 Recommendations for Further Study

FAST-1 primarily focused on impacts to residential and commercial buildings in Marsh Harbour and Treasure Cay on Great Abaco Island. 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:

- Revisit a sample of well-performing sites, preferably with local engineers, to conduct a more in-depth forensic assessment to identify specific causal factors leading to improved performance relative to surrounding structures. FAST-1 was able to document the performance on-site, and capture some specifics of the structural load paths, but time generally prevented detailed forensic investigations. There is considerable value in more fully exploring case studies of disparate damage to identify specific causal factors driving disparate performance.
- Assess the Marsh Harbour Medical Clinic and Government Building, both of which appear to have performed admirably during the passage of Dorian. The FAST-1 was unable to assess these facilities in the limited time available, but follow-up work is needed to identify details of the structural and building envelope design that allowed these to perform so well, as well as discussions with occupants/officials to identify any impacts to functionality not apparent from the exterior.
- Map gradients of the storm surge inundation in more detail with respect to the local topography, in order to relate damage observations to storm surge hazard intensity. With wind speed being nominally consistent across much of Marsh Harbour and Treasure Cay, the hazard intensity gradient is primarily driven by storm surge and wave action. Detailed gradients of the storm surge intensity are necessary for contextualizing structural performance.
- Broaden the assessments geographically to capture structure performance in surrounding cays and in Grand Bahama, where a more marked wind speed gradient was present. Certain populated cays such as Man-O-War and Elbow Cay experienced the worst of Dorian, while others such as Moore Cay and Green Turtle Cay were outside of the eyewall and the worst of the wind and surge. Sampling these cays and across Grand Bahama will enable a more complete characterization of structural performance across a broader intensity gradient, which is better for probabilistic assessment of performance.
- Evaluate the various typologies and performance levels of fenestration protection, which included systems not common in the US (e.g., wood slats). FAST-1 and the supporting VAST members noted a wide variety of fenestration protection systems, some of which appeared to perform well, likely limiting potential wind damage significantly, while others appeared to be damaged or ineffective. More detailed assessments of these fenestration protection systems would provide important guidance to locals as they rebuild, and also potentially inform construction practice in the US.
- Document instances of power pole and other lifeline infrastructure failures using the StreetView imagery to evaluate failure probability across the island. FAST-1 captured ancillary information on these structure types, but more detailed assessments could be

used to improve wind hazard estimates as well as better characterize the fragility of the power distribution system.
- Document wind hazard indicators across the impacted regions. With no reliable surface measurements of the wind speeds, wind indicators such as signs, light poles, power poles, and other simple structures can be important for validating estimated wind speed intensities. A number of light poles, for example, remained standing in Marsh Harbour, while others collapsed. Further assessment and analysis could provide upper and lower bound wind speed estimates for a number of points around the islands, improving our understanding of the true wind hazard intensity.

Based on the findings of the FAST-1 as summarized in this EARR, StEER activated a second Field Assessment Structural Team (FAST-2), specifically the mapping of storm surge inundation and resulting structural/coastal impacts and broadening of the assessments geographically to include neighboring cays and Grand Bahama Island. FAST-2 featured a blend of practitioners and researchers, including Bahamian Engineers, and was organized under three subteams:

1. **Coastal Survey Team:** Andrew Kennedy of the University of Notre Dame and James Kaihatu of Texas A&M University
2. **Door-to-Door Damage (D2D) Team:** Doug Allen of Simpson Strong-Tie and a team of Bahamian Engineers from Caribbean Coastal Services - Davon Edgecombe, Terran Brice, Kevin Brown
3. **Rapid Imaging Team:** Richard Wood of University of Nebraska, Lincoln and Henry Lester of University of South Alabama with imaging services from Mike Vorce of Site Tour 360

Between October 5-8, 2019, these subteams worked in parallel assessing strategic targets, mapping coastal storm surge, rapidly imaging developments with significant wind and storm surge damage using 360-imaging and Applied StreetView technologies, and conducting in-depth forensic assessments using StEER's mobile applications and LiDAR scanning. The geographic coverage included Great Abaco Island, Man-o-War Cay, and Grand Bahama Island. As with FAST-1, StEER partnered with the NHERI RAPID EF on FAST-2, bringing advanced rapid assessment technologies to this mission.

In addition to the themes above, StEER also recognizes the importance of investigating the topics below, which fall outside the purview of natural hazards engineering research but are nonetheless critical opportunities to learn from this disaster to inform research, policy and practice in the future. These are restated from the PVRR (Kijewski-Correa et al. 2019) to re-emphasize their importance.

TOPIC 1: Addressing informal settlements in land use planning and development
Informal settlements are a historical legacy in Latin American and the Caribbean and thus are an inescapable reality in these regions. It is well understood that the social vulnerability of these populations results in construction with equally high degrees of structural vulnerability, situated

often on undesirable land that tragically has the highest degrees of hazard exposure. Seeing this disproportionate level of risk may prompt the dismissal of the outcomes in The Mudd and Pigeon Peas as inevitable; however, the tragic lesson of these informal settlements provides an opportunity to re-examine the structural barriers facing disaster risk reduction among populations with undocumented status and without land rights. The settlements lost in Dorian were built over decades and the consequences of where survivors will settle and whether these low-lying plots of land are ever developed again will reach far beyond the memories of persons directly affected by this disaster. The survivors of The Mudd and Pigeon Peas, as well as internally displaced persons (IDPs) who now lack shelter as a consequence of Dorian, will need to be managed with innovative approaches to resettlement, regulation, and integration of informal settlements to prevent future tragedies and possibly head off the formation of high-vulnerability IDP zones in the immediate term.

TOPIC 2: Impacts of slow-progression hurricanes on storm preparedness and evacuation

Hurricane Dorian's slow progression and even stall in the Bahamas not only intensified the exposure to winds and storm surge, but also made the storm notoriously difficult to predict. With communities in multiple US states undertaking preparations and evacuations for a week or more before the storm arrived, it is important to examine the impact of Dorian "fatigue" on preparations and compliance with evacuation orders. With recent studies suggesting that slow forward speeds are becoming increasingly common (Hall and Kossin, 2019), emergency managers will need to contend with both the realities of rapidly intensifying storms in warm Gulf waters (like Hurricanes Harvey and Michael), as well as disruptions in the atmospheric circulation patterns that result in slow-moving storms like Dorian (and even the stalling of hurricanes post-landfall, such as Harvey over Houston). This dichotomy in storm characteristics makes the phasing and timing of warnings and evacuation orders increasingly difficult. Communities will similarly have to prepare for greater periods of self-sufficiency, particularly when sheltering in place, given the increasing likelihood of stalled storms.

TOPIC 3: Reframing disaster risk for small island nations

Hurricane Dorian is yet another powerful illustration of the amplified effect hurricanes of this size and intensity can have on small island nations. As was the case with Irma and Maria's impacts on the US Virgin Islands and Puerto Rico, the projected losses in Hurricane Dorian are a sizeable percentage of the annual GDP of the Bahamas and likely more when infrastructure losses are considered. This has serious implications for the recovery timeline, particularly considering the impacts to the tourism industry vital to this nation's economy. Thus the levels of acceptable risk in these settings require careful consideration. As noted by Prevatt et al. (2010), "Hurricane risk models for [the Caribbean must consider] the consequences of damage in these small islands where the economic cost of hurricane disasters can easily exceed the annual GDP of an island's economy." The relative economic impact of these events (particularly considering the extent of uninsured losses), the infeasibility of evacuations in small islands nations without vertical evacuation options, and the logistical challenges of response and recovery across archipelagos highlighted by Dorian reiterates the continued need to re-examine disaster risk reduction and emergency management strategies in the context of policy and practice for small island nations.

Appendix A: Preliminary Summary of D2D Data in Marsh Harbour

The following provides a preliminary summary of the building types and major damage levels identified by FAST-1 in Marsh Harbour. All data is preliminary until fully quality controlled and curated by the VAST.

Table A.1. Summary of the number of damage assessments by building class (Marsh Harbour)

Building Category	Count
Condominium	2
Hotel/Motel	1
Marina	1
Office	1
Professional	5
Restaurant	1
Retail	4
Service Station	1
Shed	1
Single Family	45
Unknown	1
Warehouse	2
Total	**65**

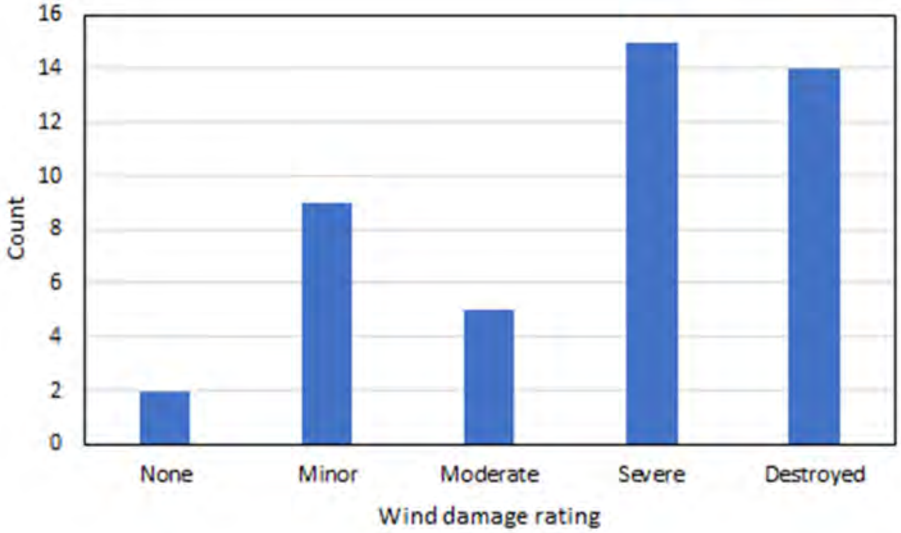

Figure A.1. Summary of wind damage ratings for single family buildings (Marsh Harbour. Total: 45)

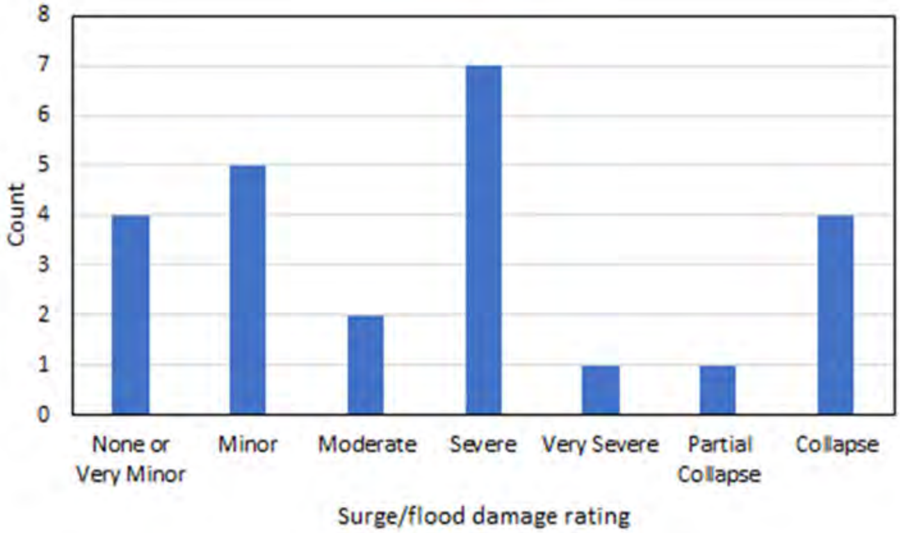

Figure A.2. Summary of surge/flood damage ratings for single family buildings (Marsh Harbour. Total: 24)

Table A.2. Summary of raw data from Fulcrum (Marsh Harbour)

S/No.	Category	Number of Stories	Wind damage rating	Surge/Flood damage rating	Rainwater ingress damage rating	First floor elevation (ft)
1	Condominium	3	Moderate	None or Very Minor		
2	Condominium		Minor	None or Very Minor		
3	Hotel/Motel		Moderate	Moderate		
4	Marina		Minor	Collapse		4
5	Office	1	Moderate	Moderate	Severe	3
6	Professional	1	None	None or Very Minor		
7	Professional	1	Destroyed	Minor		
8	Professional	2	Severe	Moderate		4
9	Professional	1	Severe	Moderate		
10	Professional	1	Moderate	Minor		
11	Restaurant	2	Moderate	Moderate		
12	Retail	1	Minor			
13	Retail		Destroyed	Severe		1
14	Retail	2	Destroyed	Moderate		1
15	Retail		Severe	Minor		
16	Service Station	1	Destroyed	Moderate		
17	Shed	1	Minor	Minor		
18	Single Family	1	Severe			
19	Single Family	1	Severe			
20	Single Family	1	Minor			
21	Single Family	1	Destroyed			
22	Single Family	1	Severe			
23	Single Family	1	Destroyed			
24	Single Family		Destroyed			
25	Single Family	2	Destroyed			
26	Single Family		Severe			
27	Single Family	1	Severe			
28	Single Family		Destroyed			
29	Single Family		Minor			
30	Single Family		Severe			
31	Single Family		Severe			
32	Single Family		Severe			
33	Single Family		Destroyed		Complete	

34	Single Family		Severe			
35	Single Family		Minor			
36	Single Family		Severe		Moderate	
37	Single Family	1	Moderate		Severe	
38	Single Family	2	Moderate	Moderate		
39	Single Family		None			
40	Single Family		Destroyed	Very Severe		
41	Single Family	2	Destroyed	Minor		
42	Single Family	2	Minor	Partial Collapse		
43	Single Family		Destroyed	Severe		
44	Single Family	1	Moderate	None or Very Minor		
45	Single Family		Destroyed	Collapse		
46	Single Family		None	None or Very Minor		
47	Single Family	2	Minor	None or Very Minor		
48	Single Family		Minor	Collapse		
49	Single Family		Minor	None or Very Minor		
50	Single Family		Severe	Severe		
51	Single Family	2	Minor	Minor		
52	Single Family	2	Severe	Minor		
53	Single Family	1	Minor	Minor		
54	Single Family	1	Severe	Severe		7
55	Single Family	1	Moderate	Severe		5
56	Single Family	2	Severe	Severe		
57	Single Family	1	Moderate	Minor		
58	Single Family	1	Destroyed	Severe		
59	Single Family	1	Severe	Severe		
60	Single Family	1	Destroyed	Moderate		
61	Single Family		Destroyed	Collapse		
62	Single Family	2	Destroyed	Collapse		4
63	Unknown		Minor	Collapse		
64	Warehouse	1	Destroyed	Moderate		
65	Warehouse	1	Destroyed	Minor		

Appendix B: Preliminary Summary of D2D Data in Treasure Cay

The following provides a preliminary summary of the building types and major damage levels identified by FAST-1 in Treasure Cay. All data is preliminary until fully quality controlled and curated by the VAST.

Table B.1. Summary of the number of damage assessments by building class (Treasure Cay)

Category	Count
Apartment	5
Condominium	4
Office	1
Pool House	1
Single Family	21
Total	**32**

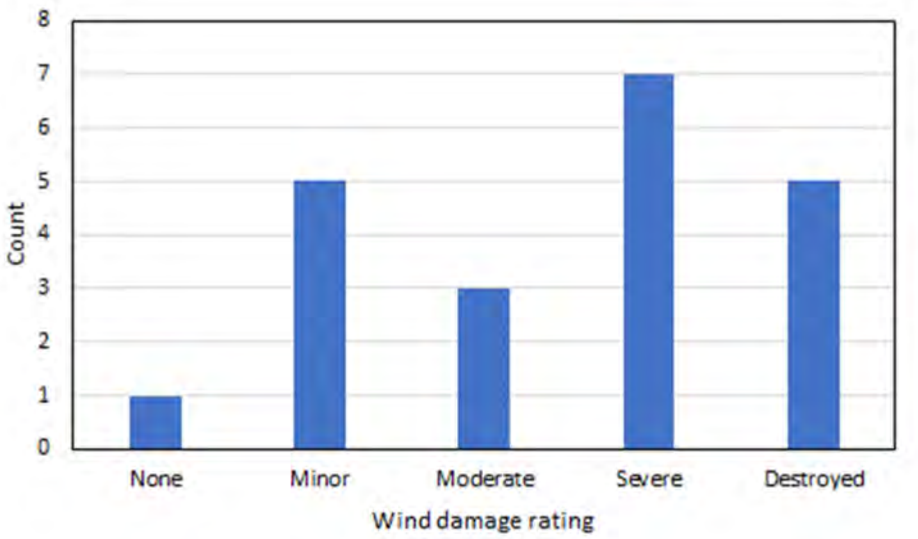

Figure B.1. Summary of wind damage ratings for single family buildings (Treasure Cay. Total: 21)

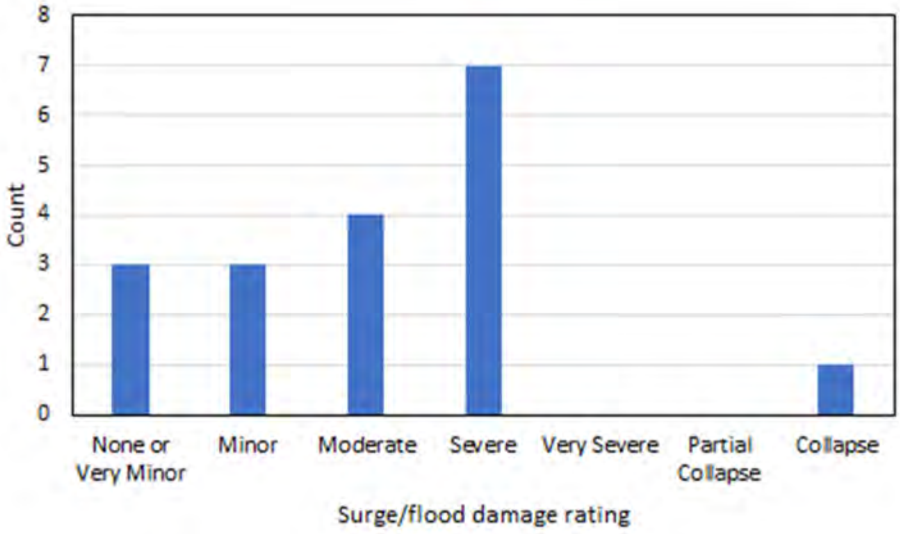

Figure B.2. Summary of surge/flood damage ratings for single family buildings (Treasure Cay. Total: 18)

Table B.2. Summary of raw data (Treasure Cay)

S/No.	Category	Number of Stories	Wind damage rating	Surge/Flood damage rating	Rainwater ingress damage rating	First floor elevation (ft)
1	Apartment		Destroyed			
2	Apartment		Moderate			
3	Apartment		Severe			
4	Apartment		Moderate			
5	Apartment		Destroyed			
6	Condominium	2	Destroyed	Moderate		
7	Condominium	2	Destroyed	Severe		
8	Condominium	2	Destroyed	Severe		
9	Condominium	2	Severe	Moderate		
10	Office	1	Severe	Moderate		
11	Pool House	1	Minor	None or Very Minor		
12	Single Family		Severe	Severe		
13	Single Family		Severe	Severe		
14	Single Family		Minor	Severe		
15	Single Family		Destroyed			
16	Single Family		Destroyed			
17	Single Family		Severe	None or Very Minor		
18	Single Family		Destroyed	Severe		
19	Single Family		Minor	Minor	Moderate	
20	Single Family		Minor		Severe	
21	Single Family	1	Severe	Severe	Severe	
22	Single Family	1	Destroyed	Collapse		
23	Single Family	1	Severe	Moderate		
24	Single Family	1	Severe	Severe	Severe	
25	Single Family	1	Moderate	Moderate		
26	Single Family	2	Destroyed	Minor		
27	Single Family	2	Moderate	Moderate		
28	Single Family	1	Moderate	Minor		
29	Single Family	1	None	None or Very Minor		
30	Single Family	1	Severe	Severe		
31	Single Family	1	Minor	Moderate		
32	Single Family	2	Minor	None or Very Minor		10

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