# HURRICANE OTIS

#### 25 October, 2023

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# PRELIMINARY VIRTUAL RECONNAISSANCE REPORT (PVRR)

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# PREFACE

The National Science Foundation (NSF) awarded an EAGER grant (CMMI 1841667) to a consortium of universities to form the Structural Extreme Events Reconnaissance (StEER) Network (see https://[www.steer.network](http://www.steer.network/) for more details). StEER was renewed through a second award (CMMI 2103550) to further enhance its operational model and develop new capabilities for more efficient and impactful post-event reconnaissance. 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.

Under the banner of the Natural Hazards Engineering Research Infrastructure (NHERI) CONVERGE node, StEER works closely with the wider Extreme Events Reconnaissance consortium to promote interdisciplinary disaster reconnaissance and research. The consortium includes the Geotechnical Extreme Events Reconnaissance (GEER) Association and the networks for Interdisciplinary Science and Engineering Extreme Events Research (ISEEER), Nearshore Extreme Event Reconnaissance (NEER), Operations and Systems Engineering Extreme Events Research (OSEEER), Social Science Extreme Events Research (SSEER), and Sustainable Material Management Extreme Events Reconnaissance (SUMMEER), as well as the NHERI RAPID equipment facility, the NHERI Network Coordination Office (NCO), and NHERI DesignSafe CI, curation site for all StEER products.

While the StEER network currently consists of the three primary nodes located at the University of Notre Dame (Coordinating Node), University of Florida (Southeast Regional Node), and University of California, Berkeley (Pacific Regional Node), StEER is currently expanding its 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, 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, 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 Coastal Hazards, serving as a primary liaison to the coastal engineering community and ensuring a robust capacity for multi-hazard assessments.
* **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.

This core leadership team works closely with StEER Research Associates, Data Librarians and its Student Administrator in event responses, in consultation with its Advisory Boards for Coastal, Seismic and Wind Hazards.

# ATTRIBUTION GUIDANCE

### Reference to PVRR Analyses, Discussions or Recommendations

Reference to the analyses, discussions or recommendations within this report should be cited using the full citation information and DOI from DesignSafe (these are available at <https://www.steer.network/responses>).

### Citing Images from this PVRR

Images in this report are taken from public sources. Each figure caption specifies the source; re-use of the image should cite that source directly. Note that public sources might still have copyright issues and depending on the use case, the user may need to secure additional permissions/rights from the original copyright owner.

# ACKNOWLEDGMENTS

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Several VAST members contributed to the corresponding Media Repository, published under a separate DOI. Their photographic evidence and analysis were vital to the production of this report:

* David Roueche, Auburn University
* Ian Robertson, University of Hawaii at Manoa
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* Hongtao Dang, Washington State University
* Tarik Lahna, University of California, Los Angeles
* Dorothy Reed, University of Washington

Special thanks to our Event Coordinator, Gabor Holtzer, and Student Administrator, Ella Gerczak, for the coordination and editorial work regarding this virtual response.

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/responses>

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## Common Terms & Acronyms

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| **Acronym** | **General Terms** | **Brief Description** |
| -- | DesignSafe | Data Repository |
| -- | DesignSafe-CI | Academic Organization within NHERI |
| ASCE | American Society of Civil Engineers | Professional Organization |
| ASTM | American Society for Testing and Materials (now ASTM International) | Standards Body |
| ATC | Applied Technology Council | Professional Organization |
| BOCA | Building Officials and Code Administrators | Code Body |
| CC-BY | Creative Commons Attribution License | Code/Standard |
| CESMD | Center for Engineering Strong Motion Data | Governmental Agency |
| CFE | Comision Federal de Electricidad = Federal Electricity Commission [in English]. | State owned electricity utility in Mexico |
| CI | Cyberinfrastructure | Research Asset |
| CLPE | Critical Load Path Elements | StEER Term |
| CMU | Concrete Masonry Unit | Building Material |
| CONAGUA | National Water Commission [English translation] | Mexican Government Agency |
| DBE | Design Basis Earthquake | Design Terminology |
| DEQC | Data Enrichment and Quality Control | StEER Term |
| DIF | National Integral Family Development System | Mexican Agency |
| DOI | Digital Object Identifier | Common Term |
| EARR | Early Access Reconnaissance Report | StEER Term |
| EERI | Earthquake Engineering Research Institute | Professional Organization |
| EEFIT | Earthquake Engineering Field Investigation Team | Professional Organization |
| EF | Enhanced Fujita Scale | Hazard Intensity Scale |
| EF | Equipment Facility | Academic Organization within NHERI |
| EIFS | Exterior Insulation Finish System | Building Component |
| FAA | Federal Aviation Administration | Governmental Agency |
| FAQ | Frequently Asked Questions | Common Term |
| FAST | Field Assessment Structural Team | StEER Term |
| FEMA | Federal Emergency Management Agency | Governmental Agency |
| FIRM | Flood Insurance Rate Maps | Regulatory Product |
| GEER | Geotechnical Extreme Events Reconnaissance | Academic Organization within NHERI |

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| GPS | Global Positioning System | Measurement Technology |
| GSA | Government Services Administration | Governmental Agency |
| HVAC | Heating, ventilation and air conditioning | Building System |
| HWM | High Water Mark | Intensity Measure |
| IBC | International Building Code | Code/Standard |
| ICC | International Code Council | Code Body |
| IFT | Federal Telecommunications Institute [English translation] | Mexican Government Agency |
| IRC | International Residential Code | Code/Standard |
| ISEEER | Interdisciplinary Science and Engineering Extreme Events Research | Academic Organization within NHERI |
| LiDAR | Light Detection and Ranging | Measurement Technology |
| MCE | Maximum Considered Earthquake | Design Terminology |
| ME&P | Mechanical, electrical and plumbing | Building System |
| MMI | Modified Mercalli Intensity | Hazard Intensity Scale |
| NBC | National Building Code | Code/Standard |
| NEER | Nearshore Extreme Event Reconnaissance | Academic Organization within NHERI |
| NFIP | National Flood Insurance Program | Government Program |
| NHERI | Natural Hazards Engineering Research Infrastructure | Academic Organization within NHERI |
| NIST | National Institute of Standards and Technology | Governmental Agency |
| NOAA | National Oceanic and Atmospheric Administration | Governmental Agency |
| NSF | National Science Foundation | Governmental Agency |
| NWS | National Weather Service | Governmental Agency |
| OSB | Oriented strand board | Construction Material |
| OSEEER | Operations and Systems Engineering Extreme Events Research | Academic Organization within NHERI |
| PEER | Pacific Earthquake Engineering Research center | Academic Organization (Earthquakes) |
| PGA | Peak Ground Acceleration | Intensity Measure |
| PHEER | Public Health Extreme Events Research | Academic Organization within NHERI |
| PVRR | Preliminary Virtual Reconnaissance Report | StEER Term |

# EXECUTIVE SUMMARY

Hurricane Otis made landfall as a Category 5 hurricane near Acapulco, Guerrero, Mexico at 6:25 UTC (12:25 AM local time) on October 25, 2023, surpassing Hurricane Patricia as the strongest landfalling Pacific hurricane on record, with measured wind speeds reaching 205 mph. Acapulco experienced significant damage, especially to residential and high-rise buildings along the coast. About 80% of the hotels in Acapulco were damaged, and about 274,000 homes were destroyed in the region. The unprecedented scale of damage to single- and multi-story buildings in low-lying regions of Acapulco resulted in dramatic failures to multiple glazing, cladding, and roof surfaces. These failures extended to nearly every high-rise structure in the nearshore region.

Over half a million electricity consumers were affected. Meanwhile, roads, ports and air transit were disrupted, limiting egressing and access to the affected coastal city. The hurricane led to a reported 45 casualties and an estimated $15 billion in damage. In the aftermath, the Mexican government proposed a recovery strategy, emphasizing immediate rescue operations, financial support, and infrastructural restoration.

This Preliminary Virtual Reconnaissance Report (PVRR) explores these topics as the primary product of StEER’s Level 1 response to Hurricane Otis:

1. overviewing of the hurricane, particularly relating to the wind and storm surge hazards and their impacts on the built environment,
2. framing the regulatory environment and construction practices in the affected area,
3. synthesizing preliminary reports of damage to buildings and other infrastructure, and
4. providing recommendations for continued study of this event by StEER and the wider engineering reconnaissance community.

Informed by the preliminary evidence compiled in this report, further research is needed to (1) characterize enhanced hurricane risk in a changing climate, where events historically atypical for this region may become commonplace, as will rapid intensifications such as those observed in Otis. This event will further support (2) ongoing study of extreme wind flow within urban canopies with important lessons to be learned for other (and even denser) urban coastal areas. This event also serves as a notable case study to (3) examine extreme wind performance of mid- and high-rise buildings assumed to be governed by seismic loads to advance our understanding of multi-hazard design. Meanwhile the extreme wind speeds observed in this event, if verified, can enable (4) validation of fragility and vulnerability models at the upper ranges of hazard intensity rarely observed to improve our overall damage and loss modeling capabilities. Finally, the topography in the region, when coupled with the heavy rains in this hurricane, provide notable cases of (5) flood-soil-structure interaction in hilly terrain.

Based on the satisfaction of a majority of the escalation criteria, StEER’s response to this event is escalated to a conditional Level 2, pending coordination with local officials and local researchers/practitioners to access impacted areas and capture perishable data through terrestrial and aerial imaging campaigns.

## Introduction

Hurricane Otis made landfall as a Category 5 hurricane near Acapulco, Guerrero, Mexico at 6:25 UTC (12:25 AM local time) on October 25, 2023 (NHC, 2023). According to the advisory archive of the National Hurricane Center (NHC), the low-pressure area was first noted on October 15, then elevated to a tropical depression by 15:00 UTC on October 22 and a Tropical storm by 22:00 UTC on the same day. The storm’s intensification went from Category 1 (50 mph) in the early hours of October 24 to Category 5 (165mph) the next day (NHC, 2023). Preliminary records from a weather station belonging to Mexico's National Tidal Service of the Institute of Geophysics indicate that peak wind gusts of about 205 mph occurred in Acapulco (Dolce, 2023).

In comparison to historical hurricane landfalls in Mexico based on sustained wind speeds, Hurricane Otis is the fourth-strongest, behind Hurricanes Janet (1955), Anita (1977), and Dean (2007). Hurricane Otis is the strongest hurricane to make landfall on Mexico’s Pacific coast, surpassing Hurricane Patricia (2016). There were major forecast errors in the storm’s category predictions and public advisories within 48 hours of landfall, as the rapid intensification of the storm was unexpected (Borenstein, 2023). Figure 1.1 shows NHC’s 3-day forecast for Hurricane Otis, which anticipated landfall as a tropical storm. It is likely that this forecast gave residents a false sense of security and may have delayed or even negated their decisions to evacuate.

**Figure 1.1** NHC 3-Day Forecast for Hurricane Otis between Monday, October 23rd, and Wednesday, October 25th. (Source: [NHC](https://www.nhc.noaa.gov/#otis))

### Societal Impact

Hurricane Otis left a trail of destruction in its wake, with powerful winds and intense rainfall, leading to widespread flooding and landslides across the region. One of the hardest-hit areas was the popular beach resort city of Acapulco, located on the Pacific coast of Mexico in the state of Guerrero. Acapulco, with a population of nearly 900,000, is the most populous city in the state and relies heavily on tourism, predominantly centered around its stunning bay area.

The impact of Otis on residential infrastructure, particularly the high-rise buildings along the coast, is starkly evident in aerial photographs of the city, showcasing significant damage to the facades of numerous structures. Figure 1.2 shows damage to the cladding of a tall building on the coast of Acapulco. The extensive nature of building cladding damage in high-rise engineered structures was of a severity making this event an outlier among recent hurricane impacts of the past two decades. According to the governor of Guerrero, the hurricane caused damage to 80% of the hotels in Acapulco, a devastating blow to the city's tourism industry (Mega et al., 2023), with another approximately 274,000 houses destroyed (Reliefweb, 2023).

**Figure 1.2.** Aerial image of a damaged building with the red box indicating an area of cladding damage ([Source Quetzalli Nicte-Ha / Reuters](https://www.cbsnews.com/news/hurricane-otis-mexico-dead-missing/))

The hurricane also took a toll on the region's essential services and infrastructure. The electric grid was severely affected, leaving 513,544 customers in the State of Guerrero without power in the aftermath of the hurricane's landfall. While efforts to restore power made progress, as of October 31, Mexico's Federal Electricity Commission reported that only 75% of the affected areas had their electricity service reinstated (CFE, 2023a). The hurricane's impact extended to communication networks as well, with phone lines and cellular phone service in the region being disrupted for a significant period, complicating emergency response and coordination. About 120 hospitals and 33 schools in the region were reported as damaged due to the hurricane event. As a result of these and other related factors, the Ministry of Education of Guerrero (SEG) decided to temporarily suspend academic activities in Acapulco and Coyuca de Benitez from October 30 to November 3 (Reliefweb, 2023).

Furthermore, road closures and the inability to access the airport due to landslides created additional challenges, causing delays in planned government and military interventions in the affected areas. Acapulco's ports were forced to close during the hurricane, disrupting not only local trade and transportation but also the city's economic activities, which rely heavily on tourism.

Reports emerged of a shortage of food and drinking water following the hurricane, primarily due to the late arrival of aid and insufficient supplies. Many grocery stores remained closed, severely limiting access to essential food items and leaving residents in a precarious position (Mega et al., 2023).

The financial implications of the hurricane's devastation are substantial. According to Enki Research, the cost of Hurricane Otis could potentially reach as high as $15 billion, underlining the extensive damage and disruption caused by this hurricane (Romero and Ore, 2023).

Additionally, one of the most salient impacts of the hurricane has been the widespread displacement of families. It was estimated that approximately 250,000 families have been left homeless because of Hurricane Otis, according to Mexico’s President Andrés Manuel López Obrador (Rivera, 2023).

### Loss of Life and Injuries

High winds and flooding pose a significant risk to the impacted community. Hurricane Otis, unfortunately, followed this pattern, resulting in a significant human toll. According to the Governor of Guerrero state, 45 people died and 47 are missing as of October 31 (Cohen, 2023). Tragically, preparedness, early warnings, and effective evacuations, which could have helped minimize the casualties, were all absent during this event. In part, this can be attributed to the failure of the NHC forecast system to anticipate the rapid intensification of the storm over warm ocean surface waters along the West coast of Mexico.

### Official Response

On the 1st of November 2023, Mexican President Andres Manuel Lopez Obrador revealed a support and recovery plan for the victims of Hurricane Otis. The general plan included rebuilding and supporting the population in Acapulco, and in the nearby city of Coyuca de Benitez, both devastated by the hurricane on October 25 (Garrison and O’Boyle, 2023).

The federal government will also reserve about $3.4 billion to implement the plan (Garrison and O’Boyle, 2023). The plan, which is composed of 20 steps, will prioritize the search for missing persons, accelerate financial support for the elderly and people with disabilities, and guarantee the support of local producers and fishermen.

The government suspended electricity payments from November 2023 to February 2024 and called for the delivery of basic foods to the estimated 250,000 families impacted by the event. Additionally, a budget will be reserved to repair houses and a package of household goods will be delivered to the victims, which includes a bed, stove, fan, and set of dishes, among other items.

Mexico is expected to receive between $30 million and $60 million from a catastrophe bond that insures the country against earthquakes and hurricanes, according to the finance minister Gabriel Yorio. He also said that Mexico has additional insurance funds available that can be used for rebuilding purposes (Garrison and O’Boyle, 2023).

### Report Scope

StEER activated a Level 1 response to evaluate this event, with a Virtual Assessment Structural Team (VAST) formed on October 25, 2023, based on the event having the strong potential to generate new knowledge (evidenced by achieving more than 50% of the activation criteria in Table 1.1). The [official response page](https://www.steer.network/response/hurricane-otis%2C-acapulco-mexico) was then instituted on the StEER website. The VAST was charged with the production of this Preliminary Virtual Reconnaissance Report (PVRR):

* + 1. overviewing of the hurricane, particularly relating to the wind and storm surge hazards and their impacts on the built environment,
    2. framing the regulatory environment and construction practices in the affected area,
    3. synthesizing preliminary reports of damage to buildings and other infrastructure, and
    4. providing recommendations for continued study of this event by StEER and the wider engineering reconnaissance community.

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| **Table 1.1.** Summary of Level 1 Activation Criteria Satisfied | | |
| **Hazard** | **Exposure** | **Feasibility** |
| * Major intensity event | * Sufficiently populated areas to create a measurable impact * Communities with a history of recovery * Noteworthy code or construction practices * Critical infrastructure * Under-documented structure classes | * Availability/interest of members * Sufficient media/social media coverage of the event, including the potential to automate the mining of information * Sufficient bandwidth for multiple concurrent responses |

## Hazard Characteristics

### Meteorological Background

Tropical Storm Otis formed on Sunday, October 22, 2023, and, based on model runs that evening local time, was predicted by the US National Hurricane Center to make landfall in the state of Guerrero near the city of Acapulco as a tropical storm (Fig. 2.1). Twenty-four hours later, the forecast remained largely unchanged, with landfall still predicted as a tropical storm, although the NHC 10 pm Discussion Number 7 mentioned the possibility of rapid intensification given the notable low-level structure and warm sea surface temperatures. Within 24 hours, that threat fully materialized with sustained winds in Otis increasing by 120 mph to bring it to Category 5 status by Tuesday night (October 24). Otis made landfall just over 24 hours later, at 12:25 AM local time. The maximum sustained winds were estimated to be 165 mph (270 km/hr), Category 5 on the Saffir-Simpson scale, and the minimum central pressure was estimated to be 923 mb. The radius to maximum winds was estimated at around 15 nautical miles at landfall by

the RAMMB Tropical Cyclone real-time analysis platform, and hurricane-force winds extended up to 30 miles (48 km) out from the center according to NHC advisories. After landfall, Otis rapidly weakened as it moved inland over Mexico until it dissipated around 4 PM local time.

Figure 2.2 shows Hurricane Otis at landfall based on water vapor as measured by the GOES-16 clean infrared product at 12:20 AM local time. A clear eye and symmetric storm structure is visible, indicating Otis remained a powerful hurricane through landfall.

**Figure 2.1.** 24-hour progression of forecasts for Hurricane Otis by the National Hurricane Center (Source: [National Hurricane Center](https://www.nhc.noaa.gov/archive/2023/OTIS_graphics.php)).

**Figure 2.2.** GOES-16 clean infrared product (band 13) as viewed at 0620 UTC (12:20 AM local time) on 10/25/2023, just before landfall (Source: [RAMMB CIRA](https://rammb-slider.cira.colostate.edu/?sat=goes-16&sec=full_disk&x=5757.5&y=7283.7861328125&z=5&angle=0&im=6&ts=1&st=20231025053020&et=0&speed=210&motion=loop&maps%5Bborders%5D=white&maps%5Bcities%5D=white&maps%5Broads%5D=purple&maps%5Bstates%5D=gold&maps%5Bstate_labels%5D=gold&maps%5Bcity_lights%5D=sodium&p%5B0%5D=band_13&opacity%5B0%5D=0.69&pause=20231025062020&slider=-1&hide_controls=0&mouse_draw=1&follow_feature=0&follow_hide=0&s=rammb-slider&draw_color=FFD700&draw_width=6&q=1)).

### Wind Field

Several permanent weather stations recorded the near-surface wind field throughout the passage of Hurricane Otis. However, StEER is unaware of the pre-deployment of any mobile surface measurement stations in Mexico. Remarkably, a Tidal Gauge Station located atop a pier at the Acapulco Terminal Maritina recorded a maximum 3-second average gust of 205 mph (330

km/hr) from the northeast. The station included a sonic anemometer positioned approximately 20 ft above water level. While verification of the measurement is still underway, if it stands, this measurement would be among the ten strongest near-surface wind gusts ever directly measured on Earth.

Two other stations also measured the passage of Hurricane Otis near landfall, one on the island of Roqueta and the other (El Veladero) further inland, on the outskirts of Acapulco. Few details are available on these stations at this time - only that the Isla Roqueta station is owned and operated by the Mexican Secretary of the Navy, and the El Veladero station is an automated weather station owned and operated by the National Meteorological Service of Mexico. Based on the provided locations, both stations appear to be in relatively built-up terrain with potential topographic effects influencing the wind and pressure measurements. In Figure 2.3, pressures have been adjusted to sea level using the elevation factor in ASCE 7. Further investigation, including site visits, of these stations would be beneficial to understanding the near-surface wind field.

### Storm Surge and Coastal Flooding

Little information is available at this time about the level of storm surge and coastal flooding induced by Hurricane Otis. Only two tidal stations were in the vicinity of the landfall region according to the National Meteorological Service of Mexico - one in the area of the Yacht Club (GPS: 16.837, -99.904), and the other being the Acapulco API station (GPS: 16.84867,

-99.90067) that was the source of the wind measurements described in Section 2.2. Only the data from the latter was able to be recovered, and it showed a minimal storm surge of about 1.5 ft (45 cm) occurred between midnight and 2:00 AM local time, which was near low tide. Water levels with the surge were similar to normal high tide levels, and no evidence of significant storm surge impacts was available at the time of this report (Fig. 2.4).

While Otis was a powerful Category 5 wind storm when it made landfall, the limited storm surge is likely due to the rapid intensification occurring just before landfall. This limits the duration of high wind speeds that would contribute to development of storm surge and large waves.

**Figure 2.3.** Surface wind and pressure measurements of Hurricane Otis from three stations in the landfall region. Wind speeds are given as nominal gusts (red) and sustained (black), but the precise averaging times, heights, and other measurement parameters are lacking at this time for all except the Acapulco API station, which was confirmed to utilize a 3-second gust averaging time and a 1-minute sustained averaging time (Source: [NOAA NCEP / Mexican Secretary of the](https://hads.ncep.noaa.gov/nexhads2/jsp/interactiveDisplays/createChart.jsp?nesdis_id=FB0127B0&nwsli=IRQG3&pe_code=UR) [Navy](https://hads.ncep.noaa.gov/nexhads2/jsp/interactiveDisplays/createChart.jsp?nesdis_id=FB0127B0&nwsli=IRQG3&pe_code=UR) and [Servicio Mareográfico Nacional UNAM](https://x.com/SMareograficoN/status/1719117506999464447?s=20)).

**Figure 2.4.** Storm tide record as measured at the Acapulco API Station (16.84867, -99.90067).

The surge was relatively low with a maximum of 1.5 feet (45 centimeters), which occurred during the low tide period. Maximum water heights in Acapulco were only slightly higher than mean high tide levels (Source: [Servicio Mareográfico Nacional UNAM](https://x.com/SMareograficoN/status/1719121190453944677?s=20)).

### Rainfall and Inland Flooding

No rain gauge data from stations in the proximity of the landfall region have been found at the time of this report. There are also no weather radar stations in the proximity of landfall, with the nearest radar located in Mexico City, nearly 185 miles (300 km) away. Satellite-derived accumulated rainfall estimates (Fig. 2.5) showed between 100-125 mm (4-5 inches) of total rainfall associated with Hurricane Otis in portions of the state of Guerrero over 24 hours ending at 3:00 PM local time (9:00 PM UTC). The heavy rainfall led to multiple reports of mudslides, particularly in the mountainous outskirts of Acapulco and surrounding regions.

**Figure 2.5.** 24-hr satellite-derived accumulated rainfall estimates in the Hurricane Otis landfall region (Source: [Meteologix.com](https://meteologix.com/ar/precipitation/guerrero/satellite-precipitation-72h/20231026-2100z.html)).

## Local Codes and Construction Practices

Designs of tall buildings in Acapulco have traditionally focused on seismic resistance due to significant past earthquakes in the region, e.g., an M7.0 earthquake struck Acapulco as recently as September 2021 (USGS, 2021), and the few major hurricanes in recent history. One of these major hurricanes, Hurricane Pauline, hit the city of Acapulco in 1997 and killed about 260 people. This hurricane was one of the deadliest Pacific hurricanes to make [landfall](https://en.wikipedia.org/wiki/Landfall_(meteorology)) in [Mexico](https://en.wikipedia.org/wiki/Mexico). Hurricane Pauline destroyed a great number of buildings, channels, culverts, streets, bridges, water pipes and sewers. This hurricane emphasized the importance of a master plan for stormwater drainage as well as the need for continued maintenance of all hydraulic facilities. Mapping of natural hazards and banning of houses and sensitive installations from risky terrain were integral parts of the ensuing risk management strategy; however, other aspects in building codes were not strengthened (Spang et al., 2003).

In fact, building codes, permitting and regulations, including design requirements, vary widely across Mexico’s 31 states and almost 2,500 municipalities (Alcocer and Castano, 2008). Each municipality is entitled by the Mexican Constitution to establish appropriate regulations, meaning that each has the power to issue its own local building code or may adopt a state building code or other design standards (e.g., ASCE 7, ACI 318, AISC). Unfortunately, a 2018 report claimed that 93% of Mexico’s municipalities have no construction regulations (MND, 2018). As such, it is not surprising to find that many of the communities affected by Hurricane Otis lacked construction regulations, so much so that significant portions of the housing in these areas were without necessities such as drainage, toilets/latrines, and electricity (Obras Redacción, 2023). The municipality of Acapulco does have building regulations in place, which were last updated

in 2002. While Acapulco also requires inspections by qualified officials to be carried out during construction and after construction has been completed (World Bank, 2016), the extent to which these regulations are enforced is unknown.

Wind resistance requirements are specified by the Acapulco Construction Regulations Chapter VII, which segregates buildings into Group A (critical facilities/essential infrastructure) and Group B (housing, offices, hotels, commercial, industrial). Most buildings fall into Group B, which requires a design wind speed of 93 mph (150 km/hr) in the coastal areas, and 62 mph (100 km/hr) further inland1. The Acapulco Regulations only specify importance factors, based on the building group, for the quantification of seismic load. Thus, the wind speeds correspond to a 50-year recurrence interval. The Construction Regulations require the wind loads to be combined with other loads using a load factor of 1.1, but load combinations are not explicitly provided.

**Figure 3.1.** 50-year return period design wind speeds for Mexico as recommended by the 2020 CFE Manual. The 50-year return period design wind speed for Acapulco is 141 km/hr (Source: CFE, 2020).

1The local Acapulco and state of Guerrero codes both specify the same wind speed; however, the basic wind speed is not defined in the local code (it is not clear if the basic wind speed is the fastest mile or the 3 second gust; many Mexican local codes still have the fastest mile in the legal publications).

In addition to the Acapulco Construction Regulations, conversations with local practicing engineers suggest that wind designs of buildings and other structures sometimes follow the Federal Commission for Electricity (CFE) Manual for Design of Civil Works (CFE, 2020), a national standard that includes wind design recommendations such as design wind speeds and wind pressure modification procedures. The CFE Manual has been adopted as the Complementary Technical Standards in some municipalities by explicit ordinances. For Acapulco, the 2020 CFE manual recommends a 50-year recurrence interval wind speed of 141 km/hr (88 mph), in contrast to and 150 km/hr (93 mph) in the 2008 version. As a result of having multiple methods for developing wind loads, and the lack of clarity in combining load cases with appropriate load factors, it is unclear what reliabilities are targeted for wind design.

## Building Performance

Tables 4.1 and 4.2 provide a synthesis of the typical performance of buildings in this event, organized by occupancy and geography. The subsections that follow present notable case studies. Readers may consult the imagery compiled in the accompanying Media Repository, curated in the same project as this report in DesignSafe, to access a richer collection of georeferenced visual evidence cataloged by occupancy.

Acapulco witnessed an unprecedented scale of damage to single- and multi-story buildings. In low-lying regions of Acapulco, high winds dominated the structural responses, inducing failures to multiple glazing, cladding, and roof surfaces. These failures extended to nearly every high-rise structure in the nearshore region. On the other hand, low-rise structures experienced significant roof damage as well as flooding caused by rainwater. In elevated regions of Acapulco, rainwater caused mudslides and foundation failures in single-story structures.

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| **Table 4.1.** Summary of Building Performance by Occupancy | |
| Single-Family Residential Buildings | Extensive damage to building inventory, including roof failures, wall collapse, foundation failure due to landslides, and wind and water damage to various structural and architectural elements. |
| Multi-Family Residential Buildings | Significant damage to the building envelope such as glazing observed in many hotels and condominiums, both along the shoreline and further inland. This resulted in almost total damage to the non-structural elements inside the buildings through wind and rain damage. No structural system failures were observed in these multi-story residential buildings. |
| Commercial Buildings | Building envelope (e.g., cladding) damage was observed in various buildings. Minor structural damage was observed at Galerias Diana shopping mall and low-rise light-framed commercial buildings. |
| Healthcare/Medical Facilities | No widespread damage was reported, but video evidence showed strong winds blowing inside a hospital in Acapulco. |

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| Schools | Significant damage to roof panels by high winds was reported in several communities;flooding of some schools was also reported. |
| Government Facilities | No observations are available for this class at the time of this report. |
| Mobile/Manufactured Homes | No observations are available for this class at the time of this report. |
| Critical Facilities | No observations are available for this class at the time of this report. |
| Historical Buildings | Roof damage was observed in historical buildings. |
| Religious Institutions | No observations are available for this class at the time of this report. |

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| **Table 4.2.** Summary of Building Performance by Geography | |
| Coyuca de Benitez | This region consists of residential houses, where the majority of the houses exhibit moderate to significant damage to their roofs and walls. |
| Puerto Marques | The area with the most significant damage, including hotels, condominiums, and Arena GNP Seguros. |
| Aeropuerto Coast Road | Severe damage was observed to building envelopes (e.g., cladding) for hotels, condominiums, stores, and other buildings in this area. |

### Single-Family Residential Structures

Acapulco witnessed severe damage to residential structures. Aerial photographs of the residential area in Coyuca de Benitez (located approximately 16 miles northwest of Acapulco) revealed extensive damage to roofs, walls, foundations, and various structural and architectural features (Fig. 4.1). The impact of blown-off roofs and walls led to widespread flooding inside houses due to water infiltration. The damage was associated with high wind loads on roofs and walls, floodwaters, and wind-borne debris.

The extent of the damage to single-family residential homes in Acapulco is lacking at this point due to limited media coverage. Based on limited satellite imagery and a few social media posts, damage appears to be widespread but dependent on the structure type, with lower-income housing with wood framing and corrugated panels suffering widespread damage.

**Figure 4.1.** Widespread roof and wall failures in Coyuca de Benitez, Guerrero. (Source: [X -](https://twitter.com/0_Mithrandir_0/status/1717890341075108239) [formerly Twitter](https://twitter.com/0_Mithrandir_0/status/1717890341075108239)).

### Multi-Family Residential Buildings

Acapulco City sits along the coast of Acapulco Bay and boasts numerous hotels, resorts, and condominiums. There was unprecedented damage to the building envelopes (e.g., glazing and cladding) of many structures due to the wind loads, though the lateral force-resisting structural systems appeared to perform adequately. Some window failures would be expected due to wind-borne debris, but generally limited to the lower levels of the buildings. However, in this case, many buildings experienced total exterior glazing loss over the full height of the building. Many buildings now display damaged roofs, loss of glazing, and failure of exterior wall cladding as a result. Examples of modern high-rise residential buildings such as the recently completed Mare Acapulco Diamante (Fig. 4.2), and the Diamante condominiums (Fig. 4.3) show extensive loss of glazing over the entire exterior of the buildings.

The Mare Acapulco Diamante building was completed in 2023, the Diamante condominiums were constructed between 2006 and 2009, and the Princess Mundo Hotel was built circa 1971. Despite the significant age gap, all displayed extensive levels of damage to multiple floors. This is surprising considering the advancements in building codes and standards that should have been taken into account during their respective constructions. Currently, there is no confirmation regarding the actual wind speed for which these buildings were designed.

Figure 4.4 shows three screenshots from a video of the damage caused to the Solar Ocean building. The first image shows a view from the unprotected balcony towards two adjacent buildings with similar exterior curtain wall failures. The middle image shows the interior of the unit with all glazing missing, severe damage to the ceiling and interior walls, and water damage

to all contents of the dwelling unit. The third image shows an exterior view confirming the exterior failure over the full building height. Figure 4.5 shows the interior of the Princess Mundo Hotel, which lost the roof glazing over the large atrium.

(a) before (b) after

**Figure 4.2.** Before and after images of the recently completed Mare Acapulco Diamante building showing almost complete loss of the exterior glazing at all building floors (Source: [Nahel Belgherze via Twitter/X](https://twitter.com/WxNB_/status/1717594733592064356)) (Location: 16.76517 N, 99.7836 W).

**Figure 4.3.** Severe damage to nearly all glazing surfaces of the condominiums in Diamante, south of Acapulco (Source: [Javier Peña via Twitter/X](https://x.com/hope_enpie/status/1717541646642905300?s=20)) (Location: 16.7754644 N, 99.7906669 W).

**Figure 4.4.** Three screen captures from a video taken inside the Solar Ocean building at 117 Costera de las Palmas, showing the complete loss of the curtain wall system of this and adjacent buildings, with major damage to non-structural interior components and building contents (Source [X - formerly Twitter](https://twitter.com/zakkumec/status/1717386214364401720?s=12&t=my25cu3D3hqxlW_L7l9OJQ)) (Location: 16.7845 N; 99.8086 W).

**Figure 4.5.** Interior views of the Princess Mundo Hotel, including loss of roof cover, destroyed glazing, and damage to interior non-structural elements. (Source: [X, formerly Twitter](https://twitter.com/volcaholic1/status/1717264491371462855)). (Location:

.16.78943 N, 99.8144663 W).

### Commercial Buildings and Stadiums

The Galerias Mall is one of the most severely damaged structures in the aftermath of Hurricane Otis (Fig. 4.6). The shopping mall encompasses commercial and shopping stores that experienced substantial damage to its roof, curtain walls, and glass cladding panels. Light framed commercial properties along the coastline in Puerto Marqués Bay provide evidence of

damage due to wind and breaking waves (Fig. 4.7). In addition, the Arena GNP Seguros (Fig. 4.8) suffered severe wind damage.

**Figure 4.6.** Exterior view of damage to the Galerias Mall. Similar to other buildings in the area, glazing was damaged by the high winds. The structural system of the building appears intact, but high winds caused severe damage to balcony railings and several partition walls (Source: Before: [Google Earth](https://earth.app.goo.gl/?apn=com.google.earth&isi=293622097&ius=googleearth&link=https%3a%2f%2fearth.google.com%2fweb%2fsearch%2fH%2526M%2C%2bAvenida%2bCostera%2bMiguel%2bAlem%25c3%25a1n%2C%2bFraccionamento%2bMagallanes%2C%2bMagallanes%2C%2bAcapulco%2C%2bGuerrero%2C%2bMexico%2f%4016.85993882%2C-99.87345734%2C13.25098419a%2C0d%2C90y%2C5.36378756h%2C113.27243175t%2C0r%2fdata%3dCtIBGqcBEqABCiQweDg1Y2E1OTNjMjZmYWM5NWI6MHgzN2IxZmViZDFhZWZlNDcZwOGqVzbcMEAhX0Q26-f3WMAqZkgmTSwgQXZlbmlkYSBDb3N0ZXJhIE1pZ3VlbCBBbGVtw6FuLCBGcmFjY2lvbmFtZW50byBNYWdhbGxhbmVzLCBNYWdhbGxhbmVzLCBBY2FwdWxjbywgR3VlcnJlcm8sIE1leGljbxgBIAEiJgokCcgA0eF_3TBAEdh5XnZv2zBAGezQ7fVU-FjAIfMj2y6t-FjAIhoKFkFVcVRUWVJNWkJ2a3pEUXNiLWV4WUEQAjoDCgEw), After: [Don Kennedy via Getty Images](https://www.gettyimages.com/detail/news-photo/general-view-of-a-shopping-mall-destroyed-after-hurricane-news-photo/1758014291)).

**Figure 4.7.** Before and after images of light commercial buildings along the coast of Puerto Marqués Bay that suffered extensive damage from both wind and wave damage (Location: 16.8026 N, 99.8363 W) (Source: Before: [Instagram](https://www.instagram.com/p/Cw0mL1wOYzF/?next=%2Fjoy_gladness_%2Ffeed%2F&hl=bn&img_index=1); After: [NPR](https://www.npr.org/sections/pictureshow/2023/10/31/1209719123/photos-see-the-aftermath-of-hurricane-otis-in-mexico)).

**Figure 4.8.** Severe damage to Arena GNP (Source: [El Sur](https://suracapulco.mx/cifras-oficiales-constatan-la-destruccion-que-ocasiono-otis/)).

## Infrastructure Performance

Tables 5.1 and 5.2 provide a synthesis of the typical performance of other infrastructure classes in this event, organized by class and geography. The subsections that follow present notable case studies. Readers may consult the imagery compiled in the accompanying Media Repository, also published under the same project in DesignSafe, to access a richer collection of georeferenced visual evidence cataloged by infrastructure class. Interested readers may also consult the Appendix for a timeline of the infrastructure restoration. An Outage/Restoration Database, curated with this report in DesignSafe, captures additional data on the disruption/outage/restoration of power, telecommunications, and transportation networks.

Notably main roads connecting Acapulco to the interior of Mexico, e.g., Mexico City, were blocked by debris and landslides; the port was inoperable, and the airport was closed. All means for leaving or supplying the affected region after the hurricane were extremely limited.

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| **Table 5.1.** Summary of Performance by Infrastructure Class | |
| Power and  Telecommunications Infrastructure | On October 26, out of 513,524 users affected, CFE restored 281, 740 (CFE Bulletin, 2023b). This is 37% of the state’s 1.4 million users. It was noted on October 29th, that 10,083 power distribution poles had been knocked down by the hurricane (CFE Bulletin, 2023c). On October 30, CFE reported that 65% of the 513,524 outages had been restored. It also noted that the Telemax power plant for communications was restored (CFE, 2023d). By October 31, CFE reported restoration of 75% of the 513,525 initial outages for Guerrero (CFE, 2023a). Acapulco originally had 284,670 outages, of which 55% (156,569) were restored. CFE did not publish bulletins after October 31. |
| Airports | The Zihuatanejo Airport was evacuated by the authorities on October 26 (UNOCHA, 2023). According to CFEmx on X, the power supply |

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|  | was fully restored by November 2nd. Failure of the exterior windows at the airport control tower resulted in water and wind damage to equipment and furniture in the tower. It is unknown how much effect this had on air traffic control after the storm. |
| Roads & Bridges | The main highway between Mexico City and Acapulco could not be accessed, which hampered electric power restoration on October 26 (UNOCHA, 2023). CFE also reported problems with power restoration due to landslides blocking roads on October 26 (CFE, 2023b). |
| Other Lifelines | Water and sanitation systems were damaged, and the municipal water system was not operating due to power outages as reported on October 26 (UNOCHA, 2023). According to the CFE Bulletin of October 30, 12 water pumps that were damaged in the hurricane were energized (CFE, 2023d). Specific locations are San Marcos, Copala, Pozos Raney del Papagayo, and Salsipuestas. Power was restored for the Raney water well on the evening of October 29. The following hospitals had their power restored by October 29: General, Military, Cancerology, and IMSS. (CFE, 2023c). |
| Port Facilities | Electricity and telecommunications were disrupted in the port area of Acapulco (UNOCHA, 2023). No further updates by Nov. 2. |
| Agricultural | No observations are available for this class at the time of this report. |

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| **Table 5.2.** Summary of Infrastructure Performance by Geography | |
| Guerrero [State] | CFE reports 513,524 outages out of 1.4 million users in the state, which is 36.6 % of the population. |
| Acapulco [City in Guerrero]. | CFE reported outages of 284,670 on October 26, of which 75% were restored by October 31. No further update available as of Nov. 2.  The Port of Acapulco and Zihuatanejo Airport also lost power. (It is not clear if these are included in the 284,670 above). Updates to their electricity status are not available from CFE as of Nov. 2. |

### Power Outages & Restoration

CFE deployed numerous resources for restoration efforts summarized in Table 5.3. These included 2,900 electrical workers, 283 cranes, 875 vehicles, 147 emergency plants, 38 lighting towers and 7 helicopters. The cranes and helicopters were needed to repair fallen towers and lines in hard-to-access terrain.

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| **Table 5.3.** The extent of Power Outage and Restoration (at time of report release) | | |
| Locale | Peak Outage | Restoration Status |
| Guerrero | 513,524 | 75% restored as of October 31 according to CFE. No further reports by CFE are available. |
| Acapulco, Guerrero | 284,670 | 55% restored as of October 31 according to CFE. No further reports by CFE are available. It is noted that although power may be restored to a region, if buildings are sufficiently damaged that they cannot receive power, the outage may never be restored. That is, the number of users will permanently decline. This scenario occurred in New Orleans, LA after Hurricane Katrina. |
| Other locations in Guerrero | Part of the overall Guerrero outages | “Reestablishment of high, medium and low voltage poles” for Avenida Costera Miguel Alaman, the City Center, Costa Azul, and Renacimiento specifically mentioned by CFE on October 30 (CFE, 2023d). |
| Source: <https://app.cfe.mx/Aplicaciones/OTROS/Boletines/boletin?i=4961> | | |

### Transportation Disruptions & Restoration

According to the United Nations Office for the Coordination of Humanitarian Affairs on October 26th, roads were so severely damaged that communities in the Acapulco area could not be accessed for restoration and recovery efforts. In addition, the main highway between Acapulco and Mexico City was inaccessible. As of November 7, locals reported that about 50% of the roads were accessible but with military restrictions. Only the military, aid vehicles, Mexican media, and people showing residency in Acapulco are allowed to enter Acapulco under military escort. Reports of road washouts were common in the more mountainous regions surrounding Acapulco, e.g., in the municipality of Kilmetro 42, Guerrero, Mexico, part of a road washed away (Fig. 5.1).

**Figure 5.1.** Roadway washed away due to erosion of the substrate by fast-moving and elevated water levels (Source: (a) [AFP Photos](http://u.afp.com/53Ch), (b) [AFP Photos](http://u.afp.com/53C7)).

Roadway damage also limited access to critical facilities such as the Acapulco Airport whose entrance road was blocked by debris (Fig. 5.2). Although the road signs and power poles were severely damaged, the “stand-alone” untethered tower in the background appears to be intact. The trees on the right-hand side of the photo appear to be debarked. Early reports by CFE stated that the airport did not have electricity and it was closed. On the evening of November 2, CFE posted on X (formerly known as Twitter) that the electricity had been restored to the airport.

**Figure 5.2.** Toppled power lines and road signs along a highway leading into Acapulco. The large billboard fell roughly parallel to the highway, indicating winds were from the East when it failed (Source:[AP Photo/Felix Marquez](https://www.cnn.com/2023/10/28/weather/hurricane-otis-death-toll-mexico/index.html)).

### Ports and Marinas

There are no major ports along the affected coastline, apart from two commercial piers inside Acapulco Bay (Locations: 16.84846 N, 99.904 W; and 16.83717 N, 99.85222 W). Neither of these facilities appears to have suffered any structural damage during the hurricane. Several recreational yacht marinas in the affected area did suffer substantial damage or complete destruction (see Figs. 5.3-5.4).

**Figure 5.3.** Google Earth images of marinas in Acapulco Bay showing complete failure of the floating docks (Location: 16.839 N; 99.907 W).

**Figure 5.4.** Images captured from video of damage to floating docks in a marina (La Marina Acapulco) in Acapulco Bay. Extensive damage has been caused to the marina, while the concrete wharf adjacent to the lighthouse appears intact (Source: [Informed Comment](https://www.juancole.com/2023/11/acapulco-destroy-infrastructure.html)).

## Geotechnical Performance

While high winds dominated glazing and cladding failures in nearshore regions of Acapulco, rainwater and flooding caused significant geotechnical damage in elevated regions. Significant disruptions to the transportation system occurred due to several rockslides above the Chilpancingo-Acapulco highway, as shown in Figure 6.1. At the road level, floodwaters caused mudslides that resulted in partial or full collapse of road lanes. Figure 6.2 presents a case where the edge of the road collapsed due to slope failure.

**Figure 6.1.** Rockslide on Route 95, Chilpancingo-Acapulco highway. (Source: [Secretaría de](https://www.gob.mx/sct/prensa/desplego-sict-personal-y-equipo-para-atender-afectaciones-de-otis-a-infraestructura-carretera-en-guerrero?idiom=es) [Infraestructura, Comunicaciones y Transportes](https://www.gob.mx/sct/prensa/desplego-sict-personal-y-equipo-para-atender-afectaciones-de-otis-a-infraestructura-carretera-en-guerrero?idiom=es)).

**Figure 6.2.** Road collapse by fast-moving floodwaters. An erosion and slope failure occurred at the edge of the road (Source: [RODRIGO OROPEZA/AFP via Getty Imag](https://www.gettyimages.com/detail/news-photo/people-pass-by-part-of-a-road-which-was-washed-away-at-the-news-photo/1745432677?adppopup=true)es).

Furthermore, residential structures located uphill around Acapulco were severely affected by soil failures caused by moving floodwaters. A number of these structures appear to rely on inadequate foundation support. As an example, Figure 6.3 shows a slope failure that resulted in the foundation collapse of a one-story residential structure.

**Figure 6.3.** Foundation failure of single-family residential structure (Source: [Rodrigo](https://www.afpforum.com/AFPForum/Search/Results.aspx?fst=kilometro%2B42%2Botis&pn=1&smd=8&mui=3&fto=1%23pn%3D1&smd=8&fst=kilometro%2B42%2Botis&fto=1&mui=3&t=2&q=18446597122658361807_1&cck=a1aff2) [Oropezia/AFP via AFP](https://www.afpforum.com/AFPForum/Search/Results.aspx?fst=kilometro%2B42%2Botis&pn=1&smd=8&mui=3&fto=1%23pn%3D1&smd=8&fst=kilometro%2B42%2Botis&fto=1&mui=3&t=2&q=18446597122658361807_1&cck=a1aff2)).

## Coastal Protective Systems Performance

This section aims to provide some insights into how Hurricane Otis affected manmade (levees, seawalls, jetties, etc.) and natural coastal protective systems that had a potential impact on the performance of the built environment in this event. Some initial description regarding the geomorphology of the region is provided to help the reader navigate the coastline close to the indicated landfall location; a separate subsection then focuses on recorded damages and the aftermath of the impact that storm surge had in the area.

### Regional coastal morphology

The affected area has a rich coastal morphology that includes the formation of natural bays (Acapulco Bay, Puerto Marques Bay, etc.), large sandy beaches that extend for miles (Los Mogotes, Luces en el Mar, Playa de Barra Vieja, etc.), rock formations that allow for smaller beaches to form (Paya mimosa, etc.), and rocky cliffs that extend to the seafront (northwestern and southeastern part of the Acapulco Bay like Punta Bruja, Punta Sirena). At least two large lakes (Laguna de Coyuca and Laguna de Tres Palos) are in the vicinity and close to the Pacific Ocean, allowing for some thin land strips to exist, hosting in some cases critical infrastructure, like the Acapulco International Airport in the southeast and a much smaller one (Pie de la cuesta).

The rich coastal morphology in the area allows for natural bays to sustain strong ocean currents and maintain their sandy beaches without the use of any significant additional infrastructure (jetties, seawalls, etc.). Owing to the orientation of long sandy beaches in the northwest of Acapulco (Los Mogotes, Luces en el Mar, Pozuelo, etc.), there is a complete lack of coastal protective systems that would be present primarily to control the sediment transport. The port of Acapulco, along with the marinas available for tourists and large cruise ships, are strategically

placed within the Acapulco Bay, leading to only some minimal construction of seawalls or some wooden decks typically within the bays and around private houses and large lodging facilities.

### Man-Made Coastal Protective Systems

The broader Acapulco area is naturally shielded by two extensive bays (Acapulco and Puerto Marques), allowing for the use of minimal coastal protective systems along the beachfront. The port of Acapulco is not used for commercial ships but used to be a cruise destination. Due to the growing criminality in Acapulco, its overall use has almost ceased entirely (Fig. 7.1). No significant damages have been reported in any of the hard coastal infrastructure (seawalls, port platforms, etc.) as recorded also by video imaging in Figure 7.2.

**Figure 7.1.** The western port area in Acapulco Bay (Source: [Google Earth](https://earth.google.com/web/search/Acapulco%2C%2BGuerrero%2C%2BMexico/%4016.84844222%2C-99.90230116%2C8.58241906a%2C1444.40333114d%2C35y%2C0h%2C0t%2C0r/data%3DCigiJgokCZeBWe07PTlAEZqBWe07PTnAGZ9LDa84m0VAIfkUJUdmOVDAOgMKATA). North is defined straight up). Some rock armor sea walls can be seen on the north side.

**Figure 7.2,** The western port area in Acapulco Bay from aerial video (Source: [X-former Twitter](https://twitter.com/ProfRayWills/status/1718436043530314078)).

### Natural Coastal Protective Systems

Acapulco is not actively enforcing any natural systems for coastal protection. The steep cliffs that exist in many areas of its coastline can be considered a natural way of protection from the strong Pacific Ocean waves, but apart from that, there is no record of any applied such systems.

## Recommended Response Strategy

Based on the information gathered by this Preliminary Virtual Reconnaissance Report (PVRR), StEER offers the following recommendations for future study.

#### Topic #1. Enhanced Hurricane Risk in a Changing Climate

1. Hurricane Otis made landfall as a powerful Category 5 hurricane in a region of Mexico not historically known for strong hurricanes. This raises the possibility of similar unexpected strikes occurring to other geographic regions, such as San Diego, California, as the climate continues to change. Basing hurricane risk assessments on models conditioned to our limited historical data leaves such communities vulnerable and under-prepared. More research is needed as to the changes in hurricane risk that can be expected with the changing climate conditions. This should include reviewing wind design standards and preparedness in major cities such as San Diego, Los Angeles, and Tijuana.
2. The rapid intensification of Hurricane Otis just before landfall joins a growing trend of such cases from recent years. This rapid intensification was not captured by any of the global hurricane models. Improving hurricane models to better capture potential for rapid intensification is a critical need, in addition to improving the communication of such risk to the public and understanding its impacts on evacuation behavior.

#### Topic #2. Extreme Wind Flow within Urban Canopies

1. The widespread failures to curtain walls and cladding systems in the high-rise buildings along the coast of Acapulco could provide critical validation data for physical or numerical wind tunnel studies of wind flow and wind-structure interaction in urban environments. That damage was frequently observed to an array of geometrically-diverse buildings, at multiple stories along the height of the buildings, and with what appear to be similar construction technologies, provides a unique opportunity to back-estimate failure wind pressures and validate models.
2. The location of the high-rise buildings downwind of the urban communities of Acapulco elevates the learning opportunities from Hurricane Otis, with applications to a wide range of similarly-positioned (and even denser) urban centers throughout the world, such as Miami, FL. Wind flow through urban canopies remains a topic with significant research gaps.

#### Topic #3. Extreme Wind Performance of Mid- and High-Rise Buildings Governed by Seismic Loads

1. Due to the history of strong earthquakes in the state of Guerrero and surrounding regions, the seismic demands on buildings in the region are high. An evaluation of the performance of seismically-governed structures, particularly mid- and high-rise buildings, under the most extreme wind speeds as produced by Hurricane Otis would be valuable to evaluate the compatibility and discrepancies between seismic- and wind-design philosophies. The design paradigms and goals for wind and seismic design can be in conflict for tall buildings due to the differences in wind and earthquake spectra (Bruneau, 2023). Such a conflict may arise for US-based critical structures built with base isolations or other seismic protection systems; it is unknown how they may perform in the event of extreme wind forces (see Hurricane Hillary).
2. It is worthy to investigate whether any buildings instrumented under strong motion networks can be identified to provide data from Otis. There may have been buildings in Acapulco whose sensors were triggered by Hurricane Otis. Evaluating the response of such buildings in Otis could improve our understanding of the response of tall buildings to extreme winds.
3. Related to extreme wind performance and the noted vulnerabilities of cladding systems, it is worthy to investigate whether the glazing used in these buildings would meet the safety requirements for fall protection in the US. Typically floor-to-ceiling exterior windows have to be laminated so that they do not shatter when broken. The piles of shattered glass observed in videos and images in the wake of Hurricane Otis suggest limited evidence of laminated window glazing. Thus forensic investigations to understand the properties of the failed curtain wall systems will not only shed important insights to improve wind-resistance, but could also highlight an area where regulatory reform could improve occupant safety in high-rise hotels and condominiums.

#### Topic #4. Verification of Extreme Winds During Hurricane Otis and Evaluation of Corresponding Fragility and Vulnerability of Communities

1. It is very rare for a storm of Hurricane Otis’ strength to maintain intensity up to landfall and strike densely populated regions. Quantification of the observed damage to various building typologies and occupancies and to critical infrastructure would provide a

much-needed dataset that encompasses the high-end of wind risk model predictions. In many such models, the performance of structures under the upper range of the hazard risk curve (e.g., >150 mph) is extrapolated based on models conditioned to observed performance at low and middle ranges of the risk hazard curve. There is a great need for high quality data under these more extreme wind environments to better condition and calibrate existing risk models. This event presents such an opportunity.

1. It is paramount that the wind measurements reported during Hurricane Otis are verified. This necessarily includes the 205 mph gust reported by a sonic anemometer in Acapulco under heavy rain conditions, but also includes several other lower wind measurements for which no metadata (instrument height, upwind terrain, measurement technology, etc) is available at this time.

#### Topic #5. Flood-Soil-Structure Interaction and Performance of Single-Story Structures Located Uphill

1. In addition to wind-induced damage, single-story structures located in elevated regions of Acapulco experienced foundation failures due to mudslides caused by moving floodwaters. A further investigation is needed into the soil type and foundation details of these structures as well as the cascading effect of soil saturation, mudslides, and subsequent structural failure. The precise rainwater conditions in these elevated locations through reported data need to be studied.

Based on the satisfaction of a majority of the escalation criteria, as summarized in Table 8.1, StEER’s response to this event is escalated to a conditional Level 2. If coordination with local officials and local researchers/practitioners can be established in a timely fashion, a Field Assessment Structural Team (FAST) will be deployed to begin a rapid assessment of the affected region using car-mounted panoramic imaging systems and unmanned aerial systems. Depending on the coordination efforts, the FAST may include Level 3 and 4 StEER members or rely primarily on local agents deploying car-mounted panoramic imaging systems. StEER is coordinating with other organizations responding to this event to further develop its field strategy.

**Table 8.1.** Summary of Escalation Criteria

|  |  |  |
| --- | --- | --- |
| **Hazard** | **Exposure** | **Feasibility** |
| *Design-Level Event.*   * Hazard intensity meets or exceeds code-mandated or PBE-adopted levels   *Unique Hazard characteristics*   * Verified upon inspection of field observations/records * Pacific Hurricane * Rapid intensification | *Infrastructure of interest*   * Highly vulnerable structures with severe damage or collapse * Highly engineered structures with lower damage states * International: practices consistent with or analogous to US practice   *Community Impacts*   * Significant fatalities * Potential for prolonged downtime and recovery | *Access and safety*   * Driving access to affected areas (conditioned on local permissions) * Safe to access if appropriate coordination can be secured. |

## Appendix: Infrastructure Restoration Timeline

|  |  |  |
| --- | --- | --- |
| Date | Damage | Source |
| 26-Oct | 1. Main highway between Mexico City & Acapulco inaccessible 2. Port electricity & telecommunications disrupted. 3. Over 500,000 homes & businesses lost power 4. Water & sanitation systems damaged and the municipal water system requires power to function properly. 5. Zihuatanejo airport evacuated. | United Nations Office for the Coordination of Humanitarian Affairs |
| 27-Oct | 1. 55% of users in Guerrero have had power restored. 2. Resources used for this: 1689 electrical workers, 161   cranes, 548 vehicles, 52 emergency plants, 21 lighting tower and 6 helicopters   1. Otis affected 513,254 users; CFE has restored 281,740. This is 37% of the state's 1.4 million users. 2. Landslides have blocked roads which has prevented workers from accessing areas. 3. Damage & anomalies in 38 high voltage lines; 15 have been restored. | CFE Press Release  CFE-BP-150/23vf  [Google Translate version] |
| 29-Oct | 1. 58% of Guerrero's 513,524 users have been restored. | CFE Press |
|  | 2. Resources deployed: 2219 electrical workers, 250 | Release |
|  | cranes, 764 vehicles, 108 emergency plants, 37 lighting | CFE-BP-151/23vf |
|  | towers and 6 helicopters | [Google Translate |
|  | 3. Municipality of Acapulco restoration at 21% or 58,887 | Version] |
|  | restored out of 284,670 affected. |  |
|  | 4. On the evening of Oct. 29, power service restored for |  |
|  | the Raney water well. |  |
|  | 5. Hospitals with restored power: General, Military, |  |
|  | Cancerology and IMSS. |  |
|  | 6. Of the 38 high voltage lines damaged, 19 have been |  |
|  | restored (50%). Of the 155 circuits, 65 have been restored, |  |
|  | i.e. 42%. |  |
|  | 7. The hurricane knocked down 10,083 poles, of which |  |
|  | 3211 have been raised (32%). |  |

|  |  |  |
| --- | --- | --- |
| 30-Oct | 1. Electrical service restored to 334,304 or 65% of the | CFE Press |
|  | 513,524 affected. | Release |
|  | 2. If only considering Acapulco municipality, 40% | CFE-BP-152/23vf |
|  | restoration or 114,152 of 284,670 users. | [Google Translate |
|  | 3. Resources for restoration: 2600 electrical workers, 280 | version] |
|  | cranes, 846 vehicles, 112 emergency plants, 37 lighting |  |
|  | towers and 7 helicopters. |  |
|  | 4. 12 water pumps energized in San Marcos and Copala, |  |
|  | as well as the pumps attached to Pozos del Raney del |  |
|  | Papagayo and Salsipuestas. |  |
|  | 5. The Telemax power plant restored that will improve |  |
|  | communications in Acapulco. |  |
|  | 6. Reestablishment of high, medium and low voltage poles |  |
|  | continue for Avenida Costera Miguel Aklaman, the City |  |
|  | Center, Costa Azul and Renacimiento. |  |
|  | 7. Emergency power plants installed for hospitals, |  |
|  | communications systems, gas stations, public security and |  |
|  | civil protection facilities. |  |
| 31-Oct | 1. Electricity has been restored to 385,951 users, which is | CFE Press |
|  | 75% of the 513,524 outages reported earlier. | Release |
|  | 2. Resources deployed for restoration: 2900 electrical | CFE-BP-154/23vf |
|  | workers, 283 cranes, 875 vehicles, 147 emergency plants, | [Google Translate |
|  | 38 lighting towers and 7 helicopters. | Version] |
|  | 3. Restoration in Acapulco municipality only: 156,569 out of |  |
|  | 284,670 users or 55%. |  |

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