Virtual Earthquake Reconnaissance Team (VERT):
Phase 1 Response to Indios, Puerto Rico M6.4 Earthquake


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Please Note: This report is based on publicly available data within 48 hours of the events. The assessment provided in the report is performed by the judgment of the authors with limited access to ground-truthing.
Topic: Earthquake Characteristics

VERT Phase 1 Response for:
Indios, Puerto Rico M6.4 Earthquake
Earthquake Characteristics

**Date:** January 7\textsuperscript{th}, 2020 at 04:24:27 am local time, 08:24:26 (UTC)

**Magnitude:** Mw 6.4 (\textsuperscript{1}USGS)

**Location:** Indios, Guayanilla, Puerto Rico
- Epicenter located 14 mi from Ponce, Puerto Rico.
- 17.916°N and 66.813°W

**Depth:** 6km\textsuperscript{2} to 10km\textsuperscript{1}

\[\text{Mw6.4 Indios Earthquake Location and Depth}\textsuperscript{2}\]
Earthquake Characteristics

Puerto Rico’s 2019-2020 winter seismic activity map and dominant faults (Ref. 11)

**Foreshock:** Jan 6 2020 (M 5.7)

**Mainshock:** Jan 7 2020 (M 6.4)

**Aftershock:** Jan 7 2020 (M 5.8)
Summary of Location, Fatalities, Fault Mechanism, and other Statistical Data

Fault Mechanism:
- The earthquake resulted from a dip-slip (normal) fault mechanism.$^4$

Max Intensity: VII$^3$
- Very Strong shaking$^3$
- Moderate damage$^3$

W-phase Moment Tensor (Mww)
USGS (2019)$^4$
Summary of Location, Fatalities, Fault Mechanism, and other Statistical Data

Impact on human safety:

- 1 fatalities reported\(^5\)
- 8 injuries reported\(^5\)
- Almost 350 people left without home\(^6\)

Impact on society:

- $838M in total economic losses, including $380M in Ponce\(^10\)
- Chuck Watson, an analyst with Georgia-based Enki Research, a disaster research group, said the quakes could cost the island up to $3.1 billion in economic losses\(^7\)

Source: Eric Rojas (2020)\(^8\)
Historical evidence prior to 2019 shows 5 destructive earthquakes that were along the major fault boundaries of the NE Caribbean and the internal blocks of the plate boundary zones. The 5/2/1787 EQ was felt throughout the island and damaged colonial buildings, especially in San Juan. The 11/18/1867 Anegada EQ damaged significantly the Virgin Islands and generated a destructive tsunami of height up to 6 m. The 10/11/1918 Mona EQ reached intensities of up to IX with a major tsunami that claimed at least 40 lives. Other significant events have occurred in 1615, 1740, 1844, 1846, 1865, 1869, 1875, 1906, 1909, 1920, 1943, 1946, 1981 and 1987. The 1/13/2014, is the first major M6 event recorded by the PRSN (Puerto Rico Seismic Network) since its establishment in the mid 70's.
Historic Seismicity and Regional Tectonic Setting

1919 EQ Puerto Rico Seismic Map (Nature, 2018)
Historic Seismicity and Regional Tectonic Setting

1918 EQ Seismic Intensity Map
(Nature, 2018)
Historic Seismicity and Regional Tectonic Setting

1918 EQ Images: Shore House pulled in sea by tsunami (left); Mayaguez Spanish Center & La Palma Restaurant (right) (Nature, 2018)
References

2 - http://www.prsn.uprm.edu/English/Informe_Sismo/myinfoGeneral.php?id=20200107082425
Topic: Building Codes

VERT Phase 1 Response for:
Indios, Puerto Rico M6.4 Earthquake
Puerto Rico’s building code was last revised in 2018, significantly revised since 2011. The codes include hazard resistant provisions that provide for safer construction in all of the island’s 78 municipalities. The current code is following the IBC model code.

FEMA provided $79 million funding for the building code update and improve code enforcement through the Hazard Mitigation Grant Program (HMGP) that enables the Planning Board and Office of Permit Management to grow their staff of 11 code compliance officers to more than 200.

Code update focused more on wind design, with 316 wind microzone maps for each municipality.

The code enforcement and code update projects modernize Puerto Rico’s building design and regulation practices. The projects represent a small part of the $3 Billion in hazard mitigation grant funding made available to PR to reduce the risk of loss of life and property from the next disaster.
Puerto Rico Building Code

- Puerto Rico Building Code (PRBC)$^2$ under the Permits Management Office (OGPe-DDEC), Department of Economic Development and Commerce of Puerto Rico.

- Building Code Years:
  - In 2011 the PRBC$^2$ adopted the 2009 IBC, referencing ASCE/SEI 7-05 with revision for the design spectral accelerations (2% in 50yr Probabilities) for the 78 municipalities of the island.
  - A revision of the PRBC$^3$ in 2018 adopted the 2018 IBC.

- Building Code Enforcement:
  - About 55% of all structures haven’t been built to code$^5$ as reported after hurricane season*
  - The vast majority of public school buildings and thousands of homes, particularly in rural areas where construction is more informal, do not comply with building codes, according to former Puerto Rico state Sen. Ramón Luis Nieves.$^6$

*It is not clear if this is seismic or wind, or both.

Spectral response acceleration (% of g) at period of 0.2 seconds, 5% critical damping, probability of exceedance of 2% in 50 years

Spectral response acceleration (% of g) at period of 1 seconds, 5% critical damping, probability of exceedance of 2% in 50 years
Comparison of actual and design accelerations

PBC 2016 (0.2 sec PSA) vs. USGS Shakemap (0.3 sec PSA)
The actual accelerations are lower than design accelerations for **shorter** periods.

PBC 2016 (1.0 sec PSA) vs. USGS Shakemap (1.0 sec PSA)
The actual accelerations are lower than design accelerations for **longer** periods.
References


Topic: Aftershocks

VERT Phase 1 Response for: Indios, Puerto Rico M6.4 Earthquake
## Summary of Aftershocks

List of aftershocks with magnitude > 4.5 [1]

<table>
<thead>
<tr>
<th>Magnitude (M)</th>
<th>Day</th>
<th>Time (UTC)</th>
<th>Location</th>
<th>Depth (km)</th>
</tr>
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<tr>
<td>5.6</td>
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<td>08:34:02</td>
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</tr>
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<tr>
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<td>01/07/2020</td>
<td>11:14:50</td>
<td>17.909°N 66.744°W</td>
<td>10</td>
</tr>
<tr>
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<td>01/07/2020</td>
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<td>18.022°N 66.776°W</td>
<td>9</td>
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<tr>
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<td>01/07/2020</td>
<td>12:54:42</td>
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<td>8</td>
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<td>01/07/2020</td>
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<td>18.014°N 66.750°W</td>
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<td>4.6</td>
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<td>16:27:07</td>
<td>17.965°N 66.826°W</td>
<td>8</td>
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</tbody>
</table>
Over the week following the Jan 7 quake, there is a 7% chance of one or more aftershocks that are larger than 6.4M. It is highly likely that there will also be many smaller earthquakes (M>3) in this period [2].

In the first 24 hours, 50 seismic events with magnitude 2.5 or higher, with 29 events more than magnitude 4 was experienced in the region. However, no tsunami threat was declared [3].

Series of aftershocks have resulted in people fearing to get back inside and using outdoor shelters instead.

Map of Puerto Rico showing seismic activity between Dec 19-Jan 20

[2]
References

Topic: Other building damage-Historical Structures

VERT Phase 1 Response for:
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Summary of other building damage

Damage to Immaculate Conception Church in Guayanilla, Constructed in 1841 [1,2]

Damage to Immaculate Conception Church in Guayanilla [4]

Damage to Exterior of Government Building in Guanica [3]
Summary of other building damage

Nonstructural Damage on Exterior of Apartment Building in Ponce (image captured from El Nuevo Dia Video) [5]

Nonstructural Damage on Exterior of Apartment Building in Ponce (image captured from El Nuevo Dia Video) [5]
References


Topic: Housing
(single-family homes)

VERT Phase 1 Response for:
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Single Family Dwellings

- Overview of damage to single-family homes
  - Most prevalent and vulnerable dwellings are concrete masonry houses typically on gravity columns, leading to soft-story mechanisms. A study of some of these vulnerable structures showed that they could not withstand the seismic demands imposed by the Uniform Building Code of 1997.¹
  - Damage to masonry walls. Most walls in residential construction are masonry walls as opposed to reinforced concrete walls.
  - The single family dwellings of two stories typically have a parking space. Several soft-story collapses were observed crushing the cars parked under the second floor.

Images from El Nuevo Dia News²

Images from Diario Libre³
References


Topic #7: Geotechnical Damage

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Summary of Geotechnical Damage

Rockslides on the westbound lanes of Ponce and Guanica [1,2]. A highway near Guanica, heading to San Juan, was blocked by large boulders that toppled off hillsides.
Summary of Geotechnical Damage

Liquefaction estimate by USGS [3]
Summary of Geotechnical Damage

Ground cracks
Guanica

Pavement cracks
Ponce

Pavement cracks
Ponce
Summary of Geotechnical Damage

Collapse of rock natural monument “Ventana al Caribe” (Punta Ventana)

Rock falling in National Route #2, near Ponce
More than 85% of the population lives within 7 km of the coast, heavily dependent on tourism from the beaches and coral reefs.

In the 1950's and 60's, PR enjoyed a construction boom, and sand and gravel were mined from beaches and rivers, causing environmental damage with beach erosion and loss of sand to nourish beaches.

Studies suggest that PR will exhaust its known supplies of onshore sand and gravel by the turn of the century.
Puerto Rico has a complex geology, with historic developments as follows:

- **130 MYA** (very early Cretaceous) - the beginning of submarine volcanism with local build up of volcanic material.
- **120 MYA** (early Cretaceous) - submarine volcanic material continues to accumulate and build up.
- **100 MYA** (late Cretaceous) - sea floor and submarine surfaces continue to build up.
- **90 MYA** (early late Cretaceous) - small volcanic island appears above sea level, the ancestral predecessor of Puerto Rico.
- **70 MYA** (end of late Cretaceous) - extensive volcanism occurs.
- **60 MYA** (Paleocene - early Eocene) - first major tectonic activity era: volcanic rocks are uplifted and eroded, becoming the source rocks for the Eocene sediments found in PR today. The island is uplifted with major NW trending strike-slip faulting.
50 MYA (middle Eocene) - sedimentary rocks are deposited throughout southern Puerto Rico.

40 MYA (late Eocene) - 2nd major tectonic activity. Island was re-elevated to alpine heights with recurrence of faulting along preexisting faults. The Esneralda fault zone developed at this time, which is the last time that major strike-slip movement occurred at the south coastal region. The Juana Diaz formation (conglomerate, shale, limey shale) formed.

25 MYA (late Oligocene - early Miocene) - 3rd major tectonic activity ear, with recurrence of faulting along preexisting northwest trending zones, but new faults also formed. The Ponce limestone formation formed.
Geology

- 15 MYA (late Miocene or younger) - 4th major tectonic activity. The island was reelevated with consequent reactivation of some old faults and the development of new ones. Block faulting with displacements up to 200 m (630 ft) occurred. Large stresses from the boundary troughs and trenches (Puerto Rico trench, Mona Passage, and Anedaga trough).

- 1-3 MYA (Pleistocene-recent) - the island is relatively stable, but continues to be under stresses with movement to the north, east-west, and south caused by Mona Passage, Puerto Rico trench, and Anedaga trough.
References

[1] https://twitter.com/Arod50051/status/1214522270271586307?s=20
Topic: Lifelines

VERT Phase 1 Response for:
Indios, Puerto Rico M6.4 Earthquake
Lifelines

- More than 300,000 users, out of 1.1 million customers, were left without water [1]. Puerto Rico aqueducts and sewer authority sent tanker trucks to serve the population.
- There was a general blackout. By January 8, half a million of disconnected users recovered the electric service [2], leaving two thirds of the population without service.
- The Costa Sur power plant, the largest plant in the system, suffered severe damage [3]. This plant is located in Valle Tallaboa, near Guayanilla. Puerto Rico was producing only 40 megawatts of electricity when demand was close to 2,000 megawatts [5]
- The capital, San Juan, remained without power for 11 hours after the earthquake [5]
- The airport of San Juan continued working, relaying on their own power generators [5]
Lifelines

- Clients without water service immediately after the earthquake, as reported by Puerto Rico Aqueduct and Sewer Authority [7]:
  - South Region 70,000
  - Metro Region 105,000
  - West Region 45,000
  - North Region 50,000
  - East Region 30,000

- Most affected systems:
  - Saint Just
  - San Martin
  - Booster
  - Venezuela
  - Campo Rico
  - Metropolis
  - Camarones
  - Bo Río
  - Treatment plant Enrique Ortega
Lifelines

- Shortage of gas in Rincon, use of gasoline delivery trucks [8]. The island is equipped with more than 70 days of regular gas, 70 days of premium gas and 130 days of diesel according to the Governor [9].
- Island residents were waiting in long lines for gas and in some places, as Caguas, they ran out of gas [10].
- The Electric Power Authority, PREPA, reported some damage to two power stations and said power plants automatically shut down to protect themselves, causing the island-wide power outage [9].
- Internet Connectivity (to #Jan08 18:00 local):
  - Many regions still effectively offline/sig. Degraded
  - < 30%: Canovanas, Lares, Jayuya, Manati, Moca
  - < 70%: San Sebastian, San German, Morovis, Vega Baja, Cayey, Fajardo, Toa Baja, Aguadilla, Carolina, Naranjito
Lifelines

- 73 sectors without power in San Juan [4] (January 8th, 20:36)
Lifelines

- Electricity lines recovery
  - By Wednesday, 500,000 customers (one-third) are back on the grid
  - Power is restored in most hospitals
  - Authorities have claimed that power will be restored to all hospitals by the weekend.
- David Begnaud (CBS correspondent) conducted an interview with Jose Ortiz, the head of the Puerto Rico Electric Power Authority, who says it may take a year to get the Costa Sur power plant back to full operation. [13]
- Mr. Begnaud was taken on a tour of the Costa Sur power plant with the facility’s operations manager, Angel Perez, who estimates that repairs will take no less than a month to complete. [14]
- CBS morning report indicated that 900,000 Puerto Ricans are without power as of the morning of 1/9/2020, while 600,000 residents do have power. [14]
- Jose Ortiz, head of the Puerto Rico Electric Power Authority, indicated that power generating equipment at Costa Sur power may be up to 60 years old. Mr. Ortiz reportedly met with FEMA officials and requested a temporary 500 MW generator. FEMA reportedly can only do so if a major declaration disaster is made. [14]
Lifelines

Pipeline repairs in Arecibo and Hatillo [6]  

Use of gas delivery trucks [8]  

Internet connectivity as of January 8, 18:00 [11]
Lifelines

Damaged Turbine at Costa Sur Power Plant [12]

Damage in Control Room at Costa Sur Power Plant [12]

Damage in Small Clean Water Tank at Costa Sur Power Plant [12]

Damage at Costa Sur Power Plant [12]
Lifelines

Fractured Pipe Connecting to Larger Water Tank at Costa Sur Power Plant, Image Captured from CBS Morning Show Video [14]

Nonstructural Damage in Costa Sur Power Plant Control Room, Image Captured from CBS Morning Show Video [14]

Damage at Costa Sur Power Plant, Image Captured from CBS Morning Show Video [14]
References

[12] Twitter, Handle @DavidBegnaud (David Begnaud, CBS correspondent): https://twitter.com/DavidBegnaud/status/1215103744582520833
[14] Twitter, Handle @DavidBegnaud (David Begnaud, CBS correspondent): Twitter (David Begnaud, local CBS correspondent): https://twitter.com/DavidBegnaud/status/1215250790576803841
Topic: Transportation Networks (including roads)

VERT Phase 1 Response for:
Indios, Puerto Rico M6.4 Earthquake
Overview of Transportation Networks

- A total of four roads were found affected by earthquake and were closed by DTOP (Department of Transportation and Public Work) [5].
- In Naranjito, the DTOP closed the PR-167 - in both directions - at kilometer 7.2 due to a landslide. Mayagüez to Aguadilla viaduct, which has two cracked columns, closed to the public for the next two weeks. In Guayanilla, the bridges located on the PR-127 km 9.1 and the one on the same road at 10.7 km are closed. DTOP also closed the bridge located in Peñuelas on PR-2 km 213 [5]. PR-333 road was also closed at Guanica.
- A bridge was damaged in Ponce on PR-52.
- A pedestrian bridge was damaged at Tallaboa Encarnacion community in Peñuelas.
- The Luis Muñoz Marín International Airport lost power in the quake and but continue on backup generators. Flights to and from San Juan, Puerto Rico operated as per scheduled after a magnitude-6.4 earthquake struck the island Tuesday morning [2].
- Earthquake triggered widespread power outages and damage affected the transportation on the road network
Overview of Transportation Networks

Viaducto Bridge @ PR-2 Mayagüez, PR Column and Cap Beam failure [6].

Cracking in a viaduct bridge column in Mayaguez on the PR-2 highway (Photo: Gerald Silva Rivera, [1]).
Overview of Transportation Networks

Column damage in a bridge on PR-52 in Ponce (Photos:Luis Aponte)
Overview of Transportation Networks

Several vehicles are stopped on a highway affected by falling stones after an earthquake, at the entrance to the city of Ponce (photo by EFE/THAIS LLORC [4])

Rocks and rubble from a landslide cover a road in Guanica after a 6.4-magnitude earthquake (Photo:Alejandro Granadillo/Anadolu Agency [3])

Mayagüez to Aguadilla viaduct closed by DTOP [5]
References


Topic: Schools

VERT Phase 1 Response for:
Indios, Puerto Rico M6.4 Earthquake
Schools Overview

● Number of schools affected:
  ○ Education officials preliminarily reported that there are at least 11 schools with structural damage [1]
● Locations:
  ○ Guanica
● Construction of the affected schools:
  ○ RC frame building
● Schools closed until reports are presented by Structural Engineers
● It is unknown when schools will be reopened.
● The governor of PR is encouraging parents to make sure the school has been inspected prior to sending their children back [13].
Schools

Timeline:

- **January 6:**
  - @11AM PR DE issues a poster on FB following EQ events (see following slide)
  - PR DE announces that School will start on Jan 13 (not Jan 9) due to seismic activities, with school staff should report on Wednesday, 8 to review emergency plans in the campuses. [12]

- **January 7:**
  - @0440 EQ event occurs
  - @0920 The secretary of Education, Eligio Hernández Pérez, has made funds available to inspect “100% of structures in the public school system.” Once structural engineers have determined the damages and certified schools that can be reopened [11]
  - @1355, PR Dept of Education (associate undersecretary, Eleuterio Alamo) announces that public schools will be closed until all evaluations have been completed by structural engineers[9, 10]
Schools Response

January 6 poster for preparedness posted on PR DES facebook page
Schools

- There are over 1,100 public schools within Puerto Rico’s 78 municipalities [2]. The figure to the right presents USGS MMI shaking intensity contours [3] overlaid on a map of school locations (Note: larger figures on next few slides)
- Approximately 30 schools experienced MMI=6.5 [2]
- Nearly 100 schools experience MMI greater than or equal to 6.0 [2]
Schools

- An operational 3-story reinforced concrete school (The Agripina Seda School) collapsed following the Mw 6.4 1/7/2020 earthquake. [1]
- The school serves 274 students (6th to 8th grades). [4]
- At the time of the earthquake, the school was closed for the Christmas holiday. Return to classes has been delayed island-wide from January 9th to the 13th. [4]
- Inspectors have been deployed to evaluate schools in the affected area. On Tuesday (1/7/2020), eleven schools with some level of structural damage had been identified, including another school in Guanica that reportedly experienced partial collapse (information unverified). [4]
- Damage to at least 3 schools has been reported in Guanica. [7]
- The Puerto Rico Department of Education released a statement that schools will not resume until all schools have been evaluated. School teachers and staff were told not to report to work, except at schools designated as shelter. [8]
Schools

Locations of Schools in Puerto Rico [2]
Locations of Schools with USGS MMI Shaking Intensity Map for Mw 6.4 1/7/2020 Earthquake
Overlaid [2,3]
Schools

Agripina Seda School, Guanica
Three-story RC Building
[1]
Schools

Agripina Seda School Collapse, Guanica
(Photo: still capture by W. Hassan off El Diario newspaper video), [1]
Schools

Agripina Seda School, Guanica [1]

Agripina Seda School, Guanica [1]

Agripina Seda School, Guanica [1]
Schools

Agripina Seda School Collapse, Guanica
[Twitter, @alwayszab]
Schools

Damage in School Reportedly Opened in 2005 (date unverified) [6]

Damage in School Reportedly Opened in 2005 (date unverified) [6]

Damage in School Reportedly Opened in 2005 (date unverified) [6]
References


[2] GIS base map provided by the National Institute of Standards and Technology (NIST) Hurricane Maria Program


References


More Information

Visit the EERI Virtual Earthquake Clearinghouse Website:
http://www.learningfromearthquakes.org/2020-01-07-puerto-rico/