Vulnerability of Schools in Puerto Rico to Tsunami Events

Transportation Infrastructure Research Center
Department of Civil and Environmental Engineering and Land Surveying
Polytechnic University of Puerto Rico

MVC, April 8, 2022

Vulnerability of Schools in Puerto Rico to Tsunami Events

Prof. Gustavo E. Pacheco-Crosetti, PhD, PE
Prof. Omaira Collazos-Ordóñez, PhD
Prof. Miriam Pabón-González, PhD, PE
Elisa Marrero-Rodríguez, BSCE, PhD Student
Verónica A. Torres Rodríguez, CE Undergraduate Student
Joel A. Cohen Vázquez, CE Undergraduate Student

Transportation Infrastructure Research Center
Department of Civil and Environmental Engineering and Land Surveying
& Undergraduate Research Program for Honor Students
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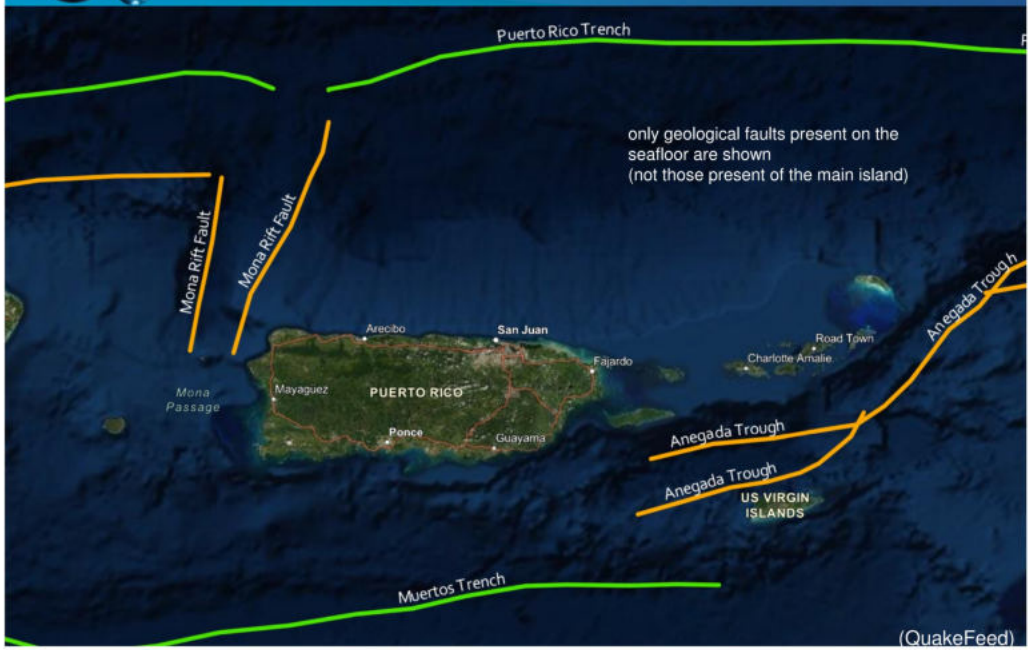
Seminar Objectives

- Contribute to the awareness on the vulnerability of PR schools (and other essential facilities) to tsunami events
- Foment the discussion on a comprehensive approach to earthquake (and multi-hazards) rehabilitation of essential infrastructure, to foster safer and more resilient communities
- Give some useful references and tools

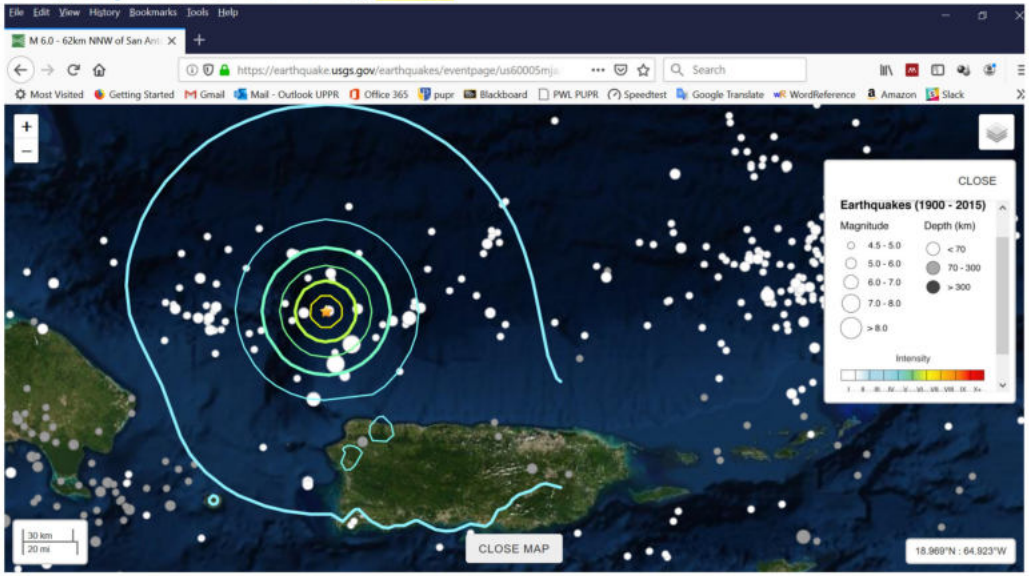
Agenda

Seismic Faults



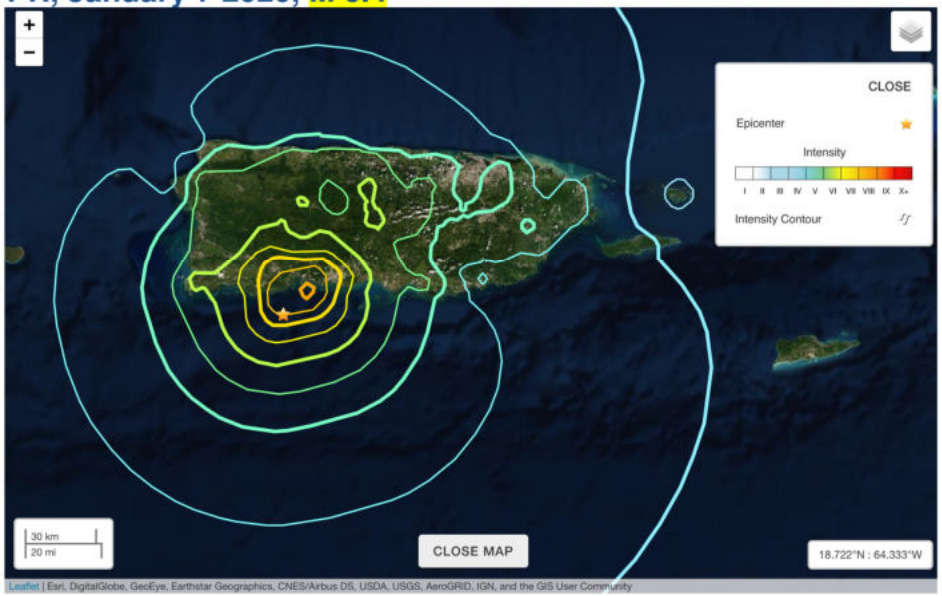
Earthquakes

PR, September 23 2019, M 6.0

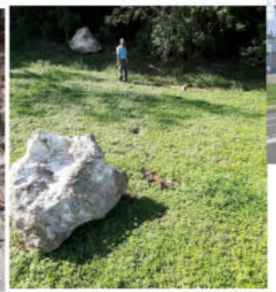


Earthquakes

PR, January 7 2020, M 6.4



Roads Damages



Landslides
Cracks on piers

Soil Effects

Liquefaction:
Sand ejecta,
sand boils,
lateral spreading

Bernal et Al, 2020

Buildings collapses and damages

Guánica, Earthquake 1/7/2020

Houses, soft story
Steel details, concrete quality, intrusive elements
(other buildings also affected)

Buildings collapses and damages

Guánica, Earthquake 1/7/2020

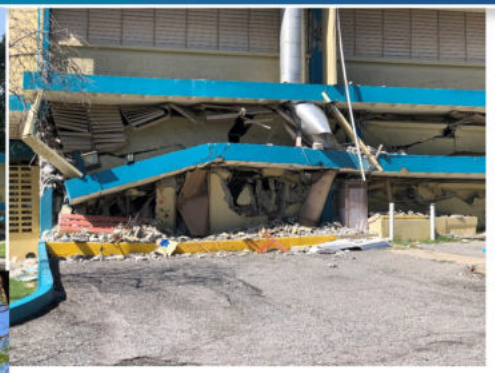
Houses, soft story
Steel details, concrete quality, intrusive elements
(other buildings also affected)

Buildings collapses and damages

Yauco, Earthquake 1/7/2020

Houses, soft story
Steel details, concrete quality, intrusive elements
(other buildings also affected)

Buildings collapses and damages

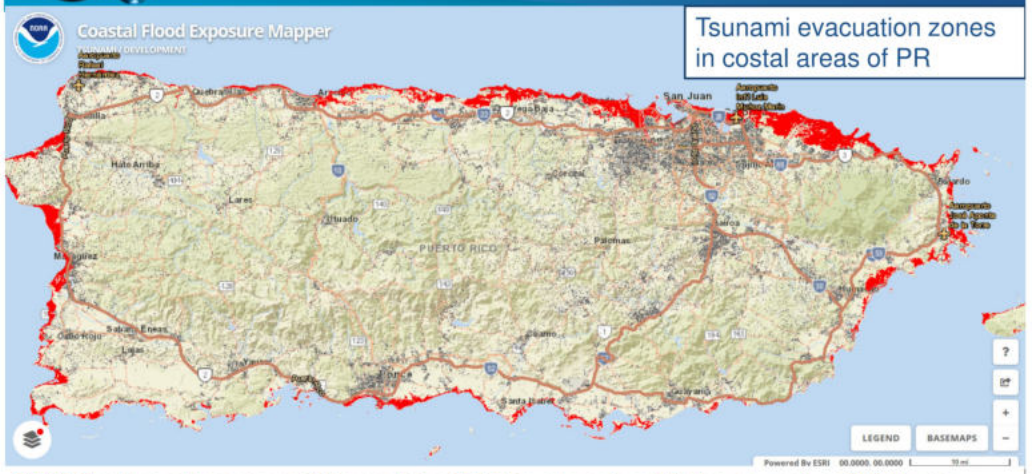


School collapse – short column

Guánica

Importance of training/practice:
Drop, Cover, Hold-on

Other impacts of Earthquakes



2020 Earthquakes were followed by R&D in structural failures and soil failures, and topics of adequate design, informal construction has re-emerged as critical.

But the topic of tsunamis protection and evacuation has not emerged as an important issue to be considered as a consequence of this events

Other impacts of Earthquakes

Table 2-1 Qualitative Tsunami Hazard Assessment for U.S. Locations, (Dunbar and Weaver, 2015)

Region	Hazard Based on Historical Record and Earthquake Probabilities	Number of Reported Deaths
Alaska	High to Very High	222
Alaska Arctic Coast	Very Low	None
American Samoa	High	34
Guam and Northern Mariana Islands	High	1
Hawaii	High to Very High	293
Puerto Rico and U.S. Virgin Islands	High	164
U.S. Atlantic Coast	Very Low to Low	None
U.S. Gulf Coast	Very Low	None
U.S. West Coast	High to Very High	25*

FEMA P-646 2019

Tsunamis

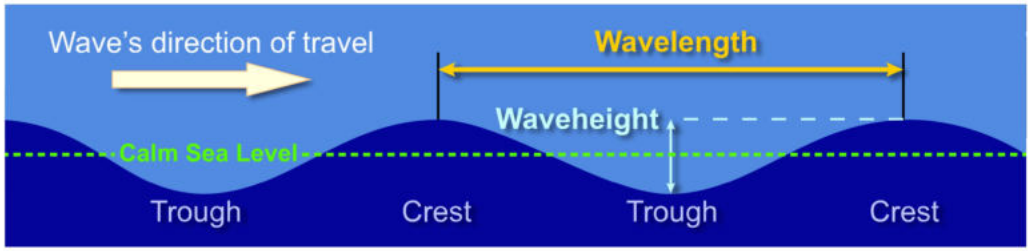
Tsunamis are generated by a sudden and large volume displacements of sea water that generates long waves that travel (propagates) fast trough the water mass

Fast Facts

津波

The word "tsunami," pronounced (soo-NAH-mee) comes from the Japanese characters meaning "harbor wave."

(https://www.weather.gov/jetstream/gen_slides)



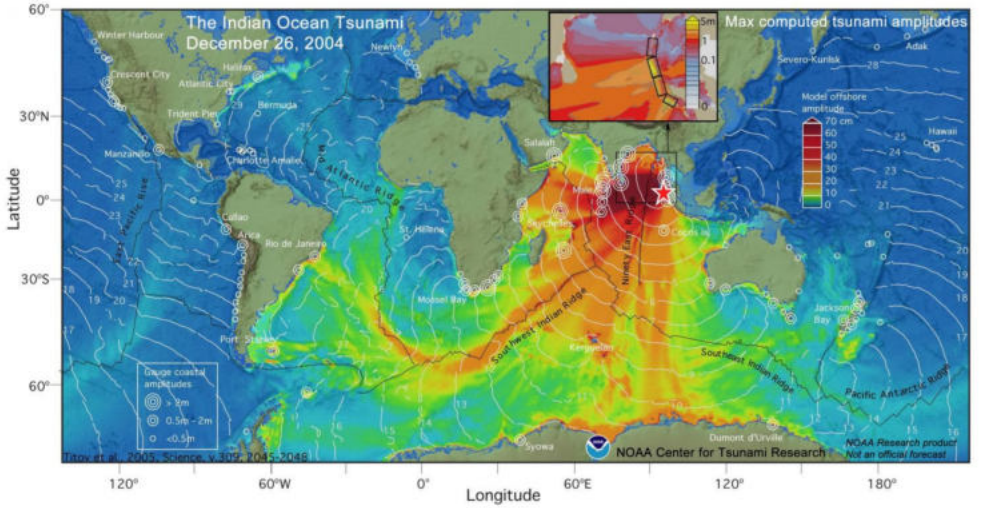
Key differences between tsunamis and wind-driven waves.

	Tsunami	Wind Wave
Source	Earthquakes, landslides, volcanic activity, certain types of weather, near earth objects	Winds that blow across the near-surface layer of the ocean
Location of Energy	Entire water column, from the ocean surface to the ocean floor	Ocean surface
Wave-length	300-600 miles (500-1,000 kilometers)	300-600 feet (90-180 meters)
Wave Period	5 minutes-2 hours	5-20 seconds
Wave Speed	Deep water: 500-600 mph (800-1,000 km/h) Near shore: 20-30 mph (30-50 km/h)	5-60 mph (8-100 km/h)

(https://www.weather.gov/jetstream/gen_slides)

"Tsunamis radiate outward in all directions from their source and can move across entire ocean basins.

Worst in history
Regional tsunami, affecting 14 countries
More than 220,000 people died or were lost

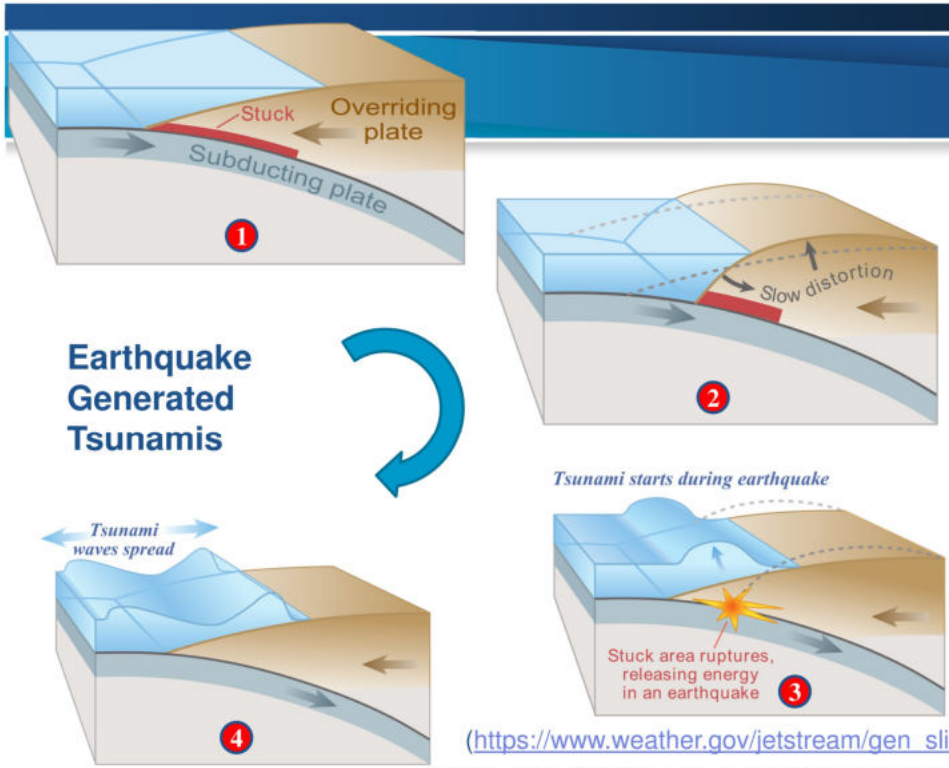


Modeled wave height (colors) and travel times (lines) of the 2004 Indian Ocean tsunami.
(https://www.weather.gov/jetstream/gen_slides)

Tsunamis

Tsunamis may be generated by (anything that produces a sudden and large volume displacements of sea water)

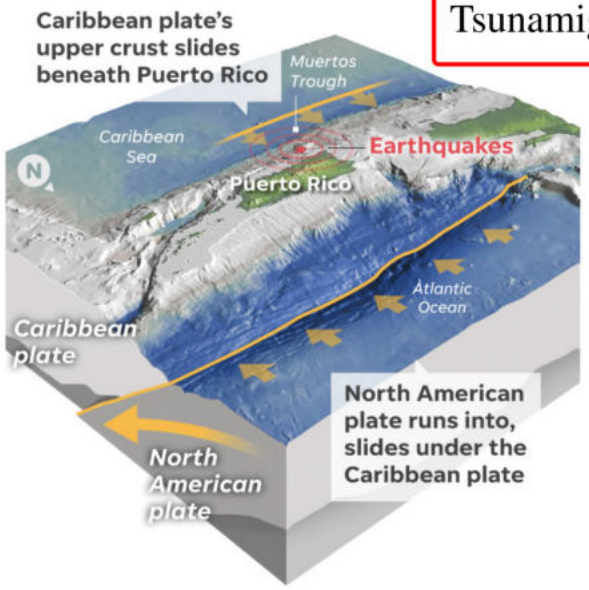
- Earthquakes
- Landslides
- Volcanoes
- Meteors



(https://www.weather.gov/jetstream/gen_slides)

Tsunamis

Tsunamigenic earthquake: M > 6.5

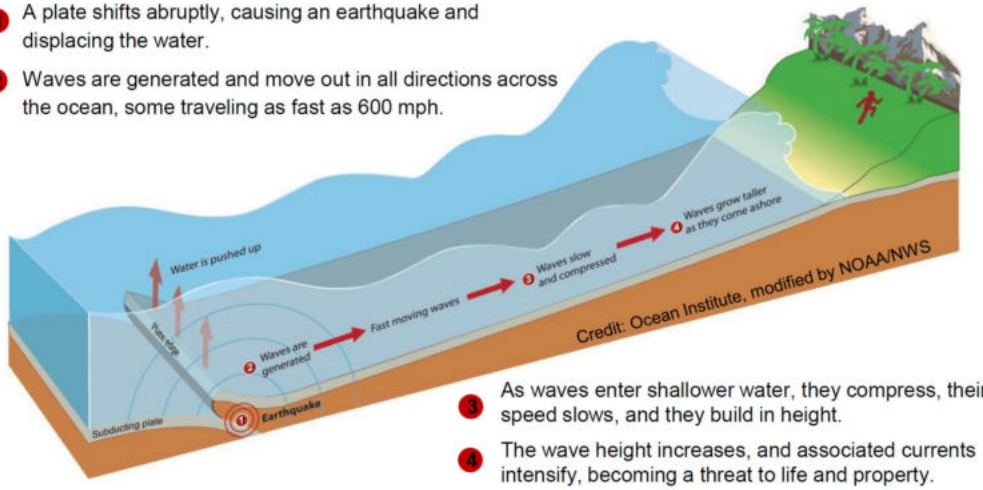


Due to expected magnitudes and vertical movement, some of PR faults has potential to generate tsunamis

From "Magnitude 5.0 earthquake strikes Puerto Rico amid ongoing aftershocks", by K. Gelles, 2020,USA Today,(https://www.usatoday.com/story/news/nation/2020/01/25/puerto-rico-earthquake-magnitude-5-0-quake-shakes-island/4576991002/). Copyright 2020 by USA Today.

Tsunamis

1. A plate shifts abruptly, causing an earthquake and displacing the water.
2. Waves are generated and move out in all directions across the ocean, some traveling as fast as 600 mph.



3. As waves enter shallower water, they compress, their speed slows, and they build in height.
4. The wave height increases, and associated currents intensify, becoming a threat to life and property.
   - coastal flooding
   - powerful currents ➔ hydrodynamic forces

www.weather.gov/tsunamisafety, **Tsunami Preparedness, Building a Weather-Ready Nation**

Tsunamis

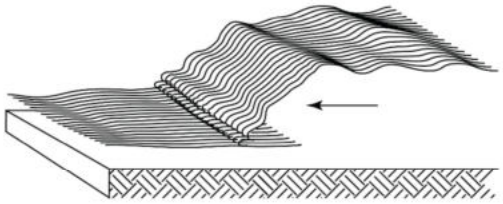


Figure 2-5 Sketch of a bore and photo from the 1983 Nihonkai-Chubu tsunami showing the formation of a bore offshore (photo from Knill and Knill, 2004). (Japan)

- "a tsunami will break offshore forming a bore or a series of bores as it approaches the shore."
- "A turbulent bore is defined as a broken wave having a steep, violently foaming and turbulent wave front, propagating over still water of a finite depth."

FEMA P-646

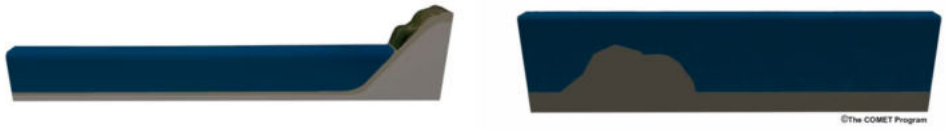
Tsunamis

March 11, 2011, Japan

https://oceantoday.noaa.gov/tsunamistrikedestruction/

Tsunamis

Landslide Generated Tsunamis
(sometimes due to earthquakes, like in PR 1918)

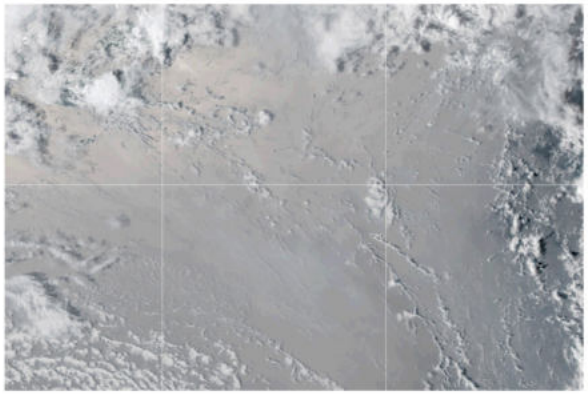


©The COMET Program

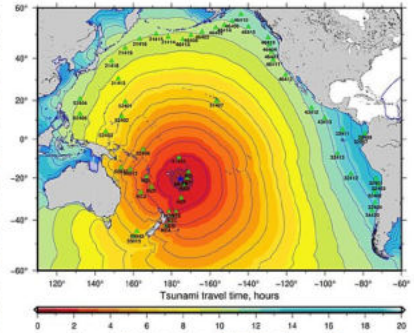
(https://www.weather.gov/jetstream/gen_slides)

Tsunamis

Volcanoes Generated Tsunamis (Pyroclastic material + landslides)



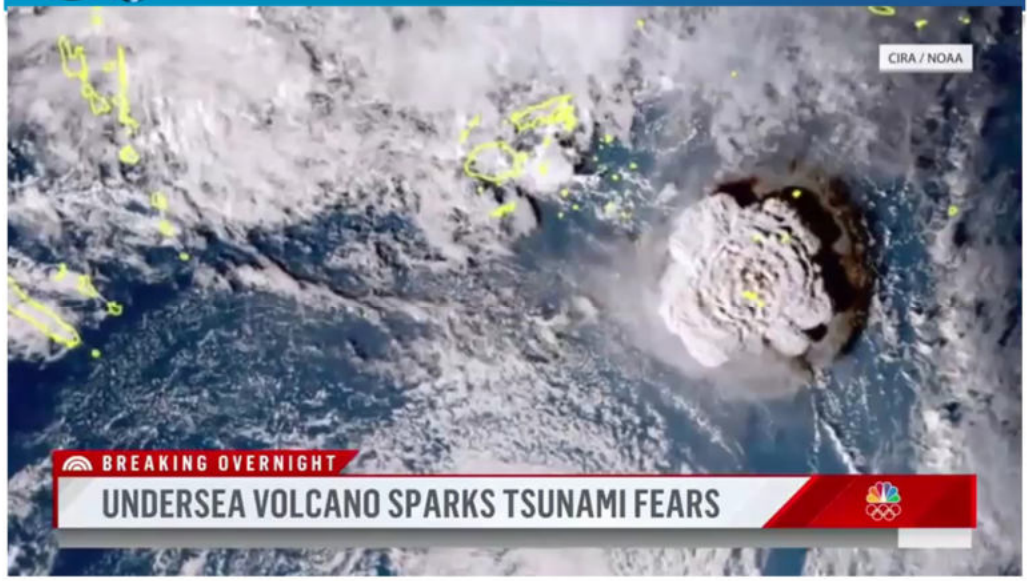
https://www.space.com/tonga-volcano-eruption-yields-asteroid-impact-insights



https://en.wikipedia.org/wiki/2022_Hunga_Tonga_eruption_and_tsunami

15 January 2022, Hunga Tonga–Hunga Ha'apai, in the South Pacific

Tsunamis



https://www.youtube.com/watch?v=ea-S87dRpLw

Tsunamis Effects

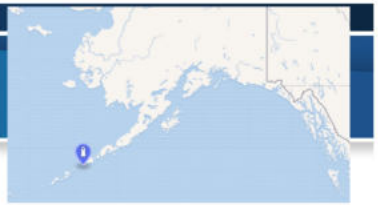


Figure 2-9 Scotch Cap Lighthouse destroyed by the 1946 Aleutian Tsunami.

FEMA P-646

Scotch Cap, Unimak Island, Alaska

Tsunamis Effects

Figure 2-10 Total destruction of a group of wood-frame houses in Aonae Village, Okushiri Island, Japan (1993 Okushiri Tsunami).

FEMA P-646

Tsunamis Effects

Figure 2-11 Beach houses with varying levels of damage in El Popoyo, Nicaragua (1992 Nicaragua Tsunami). All three houses are in the same vicinity.

FEMA P-646

Tsunamis Effects

Figure 2-12 Damage caused by impact from water-borne debris (fishing boat) in Aonae, Japan (1993 Okushiri Tsunami) (photo courtesy J. Preuss).

FEMA P-646

Tsunamis Effects

Figure 2-16 Examples of waterborne debris from the 2004 Indian Ocean Tsunami (photos courtesy of M. Saatcioglu, A. Ghobarah and I. Nistor, CAEE, 2005).

FEMA P-646

Figure 2-22 Scene of near-total devastation in Minamisanriku, Japan, 2011 Tohoku tsunami (photo courtesy of I. Nistor and ASCE, from Chock, et al., 2013b).

Example of surviving reinforced concrete mosque in Uleele, Banda Aceh (photo courtesy J. Borerro).

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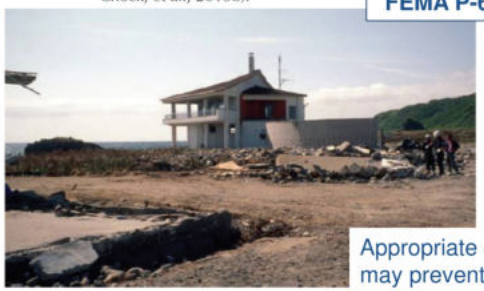
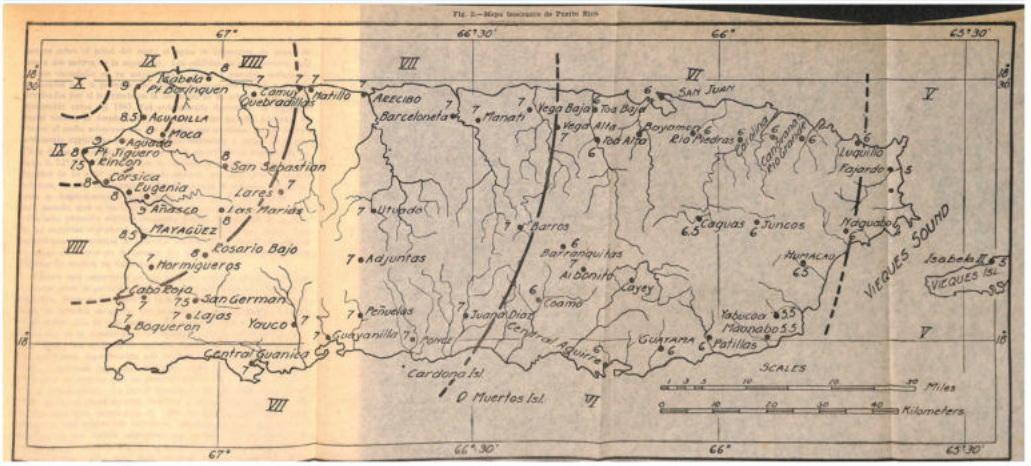


Appropriate design may prevent collapse

Figure 2-13 Examples of reinforced concrete structures that survived the 1993 Okushiri Tsunami: vista house at Cape Inaho (left); and fish market in Aonae (right) (photo courtesy N. Shuto).

Tsunamis in PR



Intensidades, escala Rossi-Forel (Los Terremotos de Puerto Rico de 1918 Harry Fielding Reid & Stephen Taber)

11 de octubre de 1918, el día de San Fermín, M 7.3

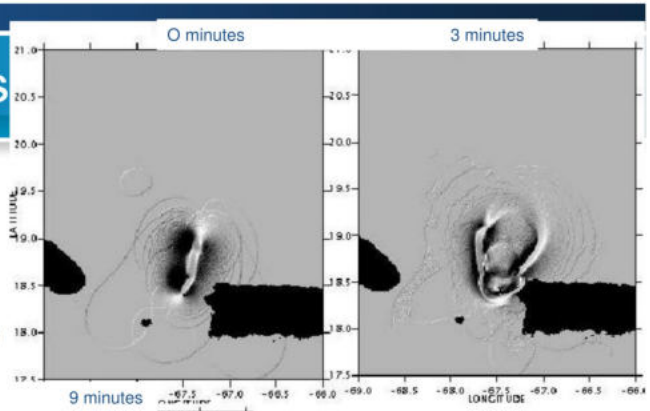
116 persons lost their lives, and the property loss amounted 4 M
(THE PORTO RICO EARTHQUAKE OF 1918 66th CONGRESS 1st SESSION MAY 19 NOVEMBER 19, 1919)

Tsunamis

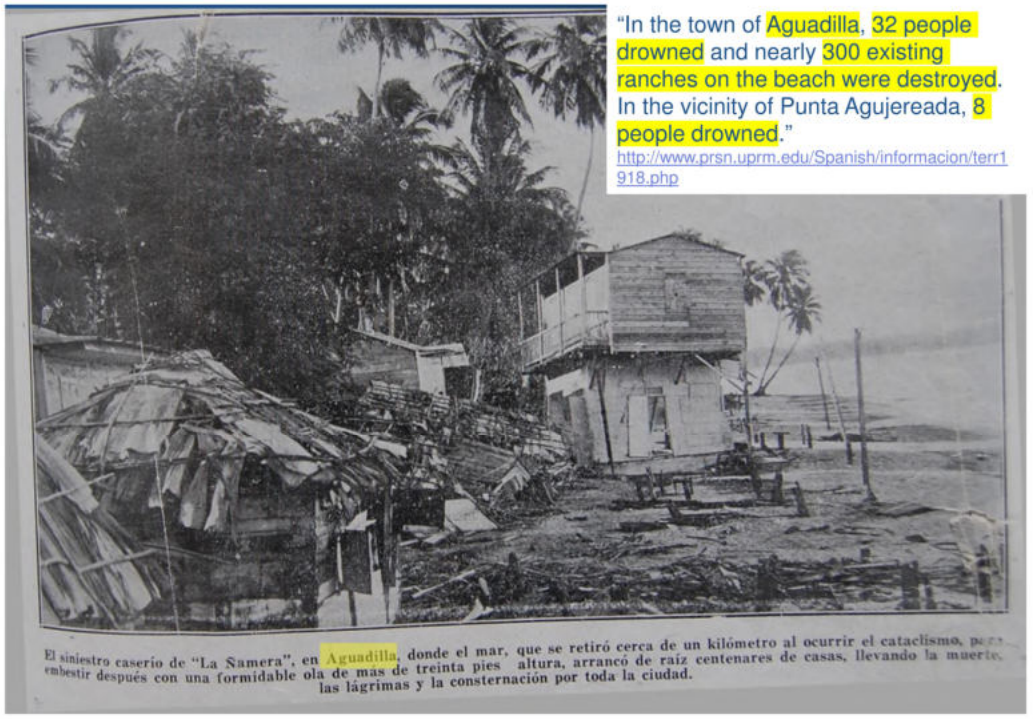
NUMERICAL SIMULATION OF THE 1918 PUERTO RICO TSUNAMI

A. Mercado, and W. McCann

https://redsismica.uprm.edu/english/education/earthquakes/1918earthquake.php



"Near Punta Agujereada (Aguadilla) the elevation of the wave was calculated between 5.5 and 6.0 meters (approximately 20 feet). Estimates of the time elapsed between the earth tremor and the arrival of the sea wave were 4 to 7 minutes."
http://www.prsn.uprm.edu/Spanish/informacion/terr1918.php

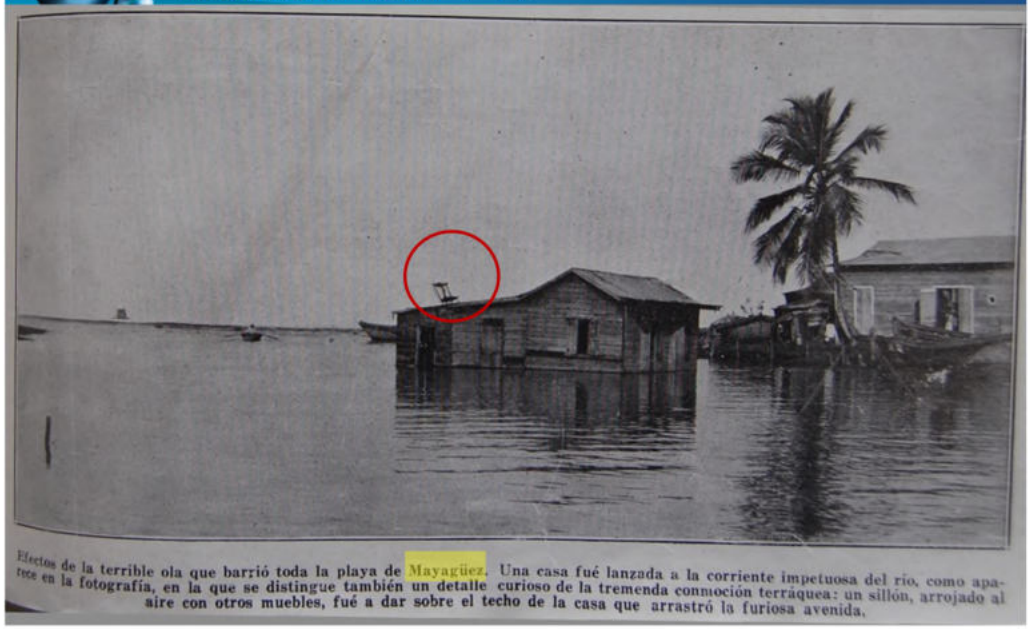


"In the town of Aguadilla, 32 people drowned and nearly 300 existing ranches on the beach were destroyed. In the vicinity of Punta Agujereada, 8 people drowned."
http://www.prsn.uprm.edu/Spanish/informacion/terr1918.php

El siniestro caserío de "La Samera", en Aguadilla, donde el mar, que se retiró cerca de un kilómetro al ocurrir el cataclismo, para embestir después con una formidable ola de más de treinta pies de altura, arrancó de raíz centenares de casas, llevando la muerte, las lágrimas y la consternación por toda la ciudad.

Puerto Rico Ilustrado, Octubre 19 de 1918 (del Archivo Digital Nacional de Puerto Rico)

Tsunamis in PR



Efectos de la terrible ola que barrió toda la playa de Mayagüez. Una casa fué lanzada a la corriente impetuosa del río, como aparece en la fotografía, en la que se distingue también un detalle curioso de la tremenda conmoción terráquea: un sillón, arrojado al aire con otros muebles, fué a dar sobre el techo de la casa que arrastró la furiosa avenida.

Puerto Rico Ilustrado, Octubre 19 de 1918 (del Archivo Digital Nacional de Puerto Rico)

Tsunamis in PR

Fig. 6 (a).—Casas arrojadas unas contra otras por las olas.

(Photos from: Los Terremotos de Puerto Rico de 1918 Harry Fielding Reid & Stephen Taber)

Tsunamis in PR

Fig. 6 (b).—Casa arrastrada por las olas.

(Photos from: Los Terremotos de Puerto Rico de 1918 Harry Fielding Reid & Stephen Taber)

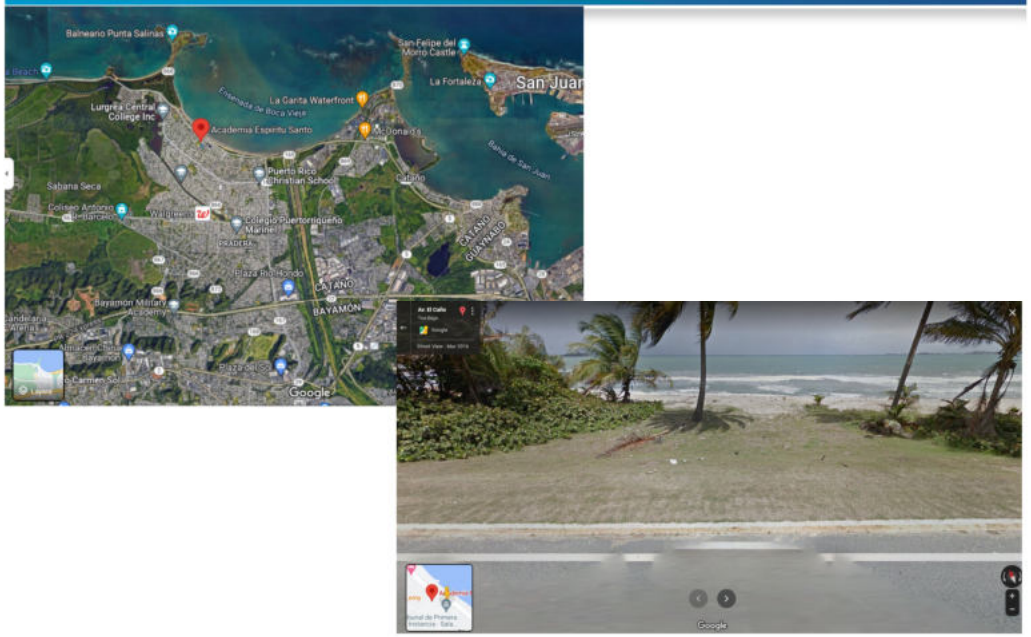
Tsunamis in PR

(Photos from: https://www.bbc.com/mundo/noticias-45793382 / Red Sismica de PR)

Coastal Schools in PR

Coastal Schools in PR

Coastal Schools in PR



Problem Statement

There is a potential impact of tsunamis on schools' population

Number of Schools in Puerto Rico (2015-2016)		
Public Sector	Private Sector	Total
1,418	795	**2,213**

Population of Schools in Puerto Rico (2015-2016)			
	Public Sector	Private Sector	Total
Students	417,101	142,235	559,336
Teachers	33,700	11,536	45,236
			≅ 600,000

Disdier Flores, O. M., & Cruz Soto, L. J. (2019). *Anuario Estadístico Del Sistema Educativo* (2016th ed.). Instituto de Estadísticas del Gobierno de Puerto Rico.

Agenda

1. Introduction - Motivation
2. Stage I - Completed
3. Stage II - Ongoing
4. Further Recommendations
5. References

Stage I Team

- Students
  - Verónica A. Torres Rodríguez (Undergraduate CE Student)
  - Joel A. Cohen Vázquez (Undergraduate CE Student)
- Faculty
  - Gustavo Pacheco-Crosetti, PhD, PE
  - Omaira Collazos-Ordoñez, PhD
- Undergraduate Research Program for Honor Students (URP-HS)
  - Department of Education, Grant Title V STEM Grant "Bridges to STEM Success"

Objectives

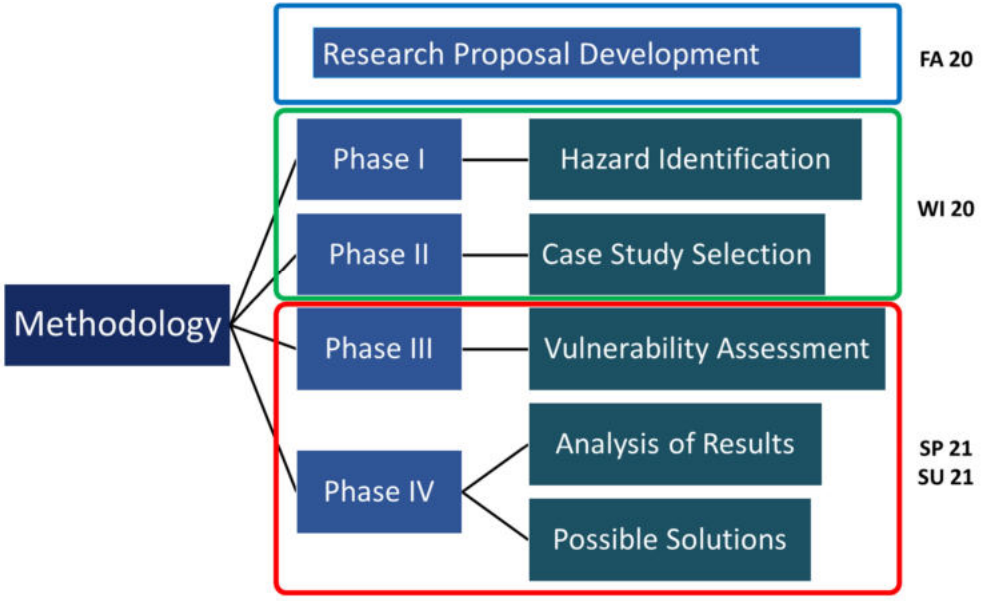
General Objectives

- Evaluate if schools in Puerto Rico are vulnerable to tsunamis

Specific Objectives

- Identify schools in areas of tsunami hazard
- Apply a methodology to assess the most vulnerable schools
- Evaluate vulnerability conditions, explore mitigation alternatives to reduce risk, and identify further studies

Methodology



Methodology - Phase I Hazard Identification

Phase I

Hazard identification

Schools

- Shelters
- Voting Centers
- Population

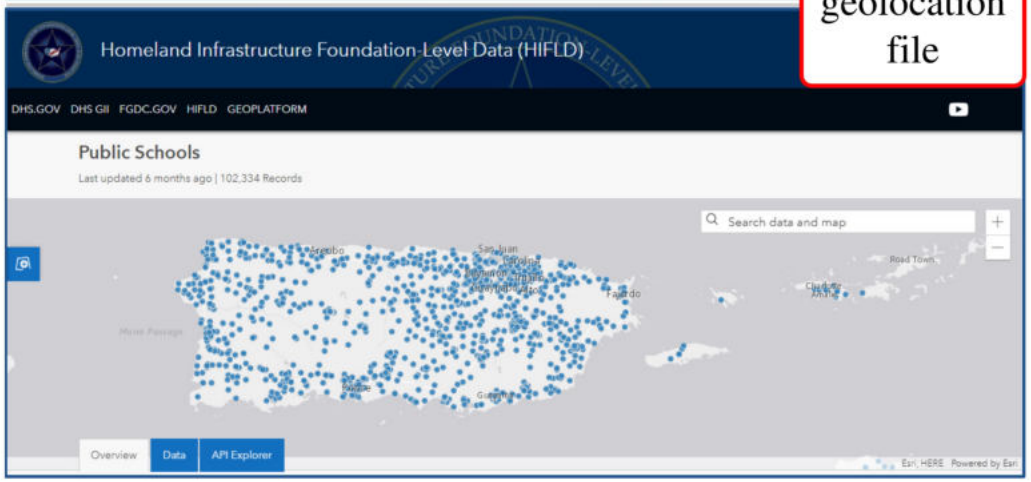
Data Collection and Analysis

- Data Collection
- Data Processing
- Findings
- Problems Encountered

(Note: shelter means “albergue” more than “refugio”)

Data Collection

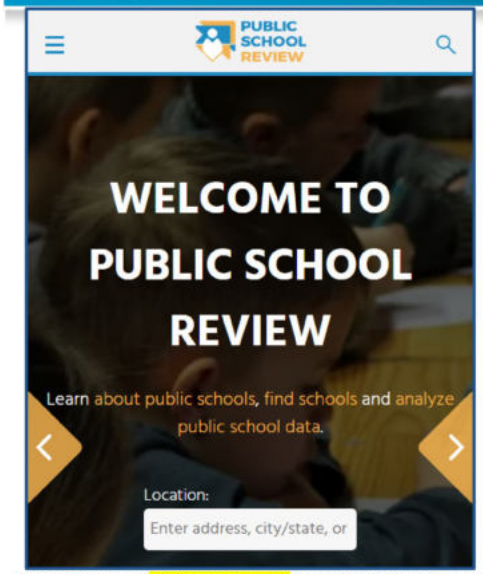
Public school's geolocation file



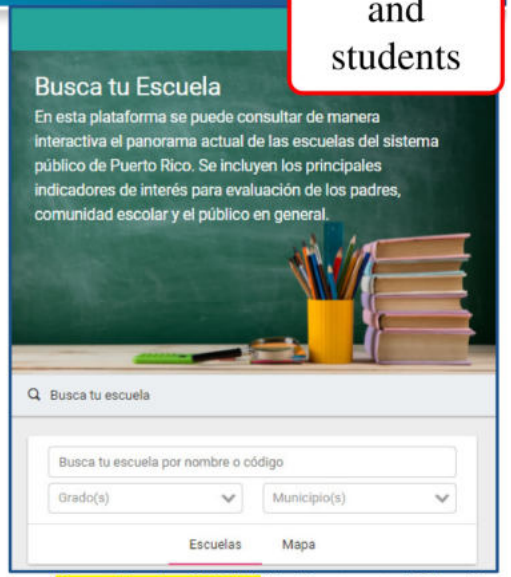
From “Public Schools,” by Homeland Infrastructure Foundation-Level Data, 2020, Homeland Infrastructure Foundation-Level Data, (https://hifld-geoplatform.opendata.arcgis.com/datasets/public-schools?geometry=-67.882%2C17.736%2C-64.213%2C18.649). Copyright 2017 by U.S. Department of Homeland Security.

Data Collection

Population of teachers and students



From “Welcome to public school review,” by Public School Review, n.d., Public School Review, (https://www.publicschoolreview.com/). In the public domain.



From “Busca tu Escuela - 2018-2019,” by Departamento de Educación, n.d., Busca tu Escuela, (https://buscatuescuela.dde.pr/). Copyright 2019 by Departamento de Educación.

Data Collection

Schools used as shelters

MUNICIPIO	ZONA AEMEAD	REGIÓN EDUCATIVA	ESCUELA	CÓDIGO	FACILIDADES	CAPA	CAPA
Adjuntas	Ponce	Ponce	1	50294	Esc. José Emilio Lugo	137	274
Adjuntas	Ponce	Ponce	1	54551	Esc. Rafael Aparicio Jimenez	102	204
Aguada	Aguadilla	Mayaguez	1	46086	Esc. Eladio Tirado López	150	300
Aguada	Aguadilla	Mayaguez	1	47951	Esc Intermedia Prof. Juana Rosario	150	300
Aguada	Aguadilla	Mayaguez	1	46813	Esc. Lydia Meléndez (Elem. Urb. Nueva)	239	478
Aguada	Aguadilla	Mayaguez	1	40220	Esc. S.U. Epifanio Estrada	120	240
Aguadilla	Aguadilla	Mayaguez	1	46656	Esc. Benito Cerezo Vázquez	87	174
Aguadilla	Aguadilla	Mayaguez	1	47647	Esc. Sup. Juan Suárez Pelegrina	250	500
Aguadilla	Aguadilla	Mayaguez	1		Esc.Conchita Igartua de Suarez	70	140
Aguas Buenas	Caguas	Caguas	1	27540	Esc. Dr. Pedro Albizu Campos (Int.)	80	160
Aguas Buenas	Caguas	Caguas	1	25783	Esc. Luis Muñoz Marín	120	240
Aguas Buenas	Caguas	Caguas	1	28571	Esc. Superior Urbana	120	240
Aibonito	Caguas	Caguas	1	20289	Esc. Dra. Carmen D Colon	350	700
Aibonito	Caguas	Caguas	1	20362	Esc. Superior Dr. José N. Gándara	250	500

From “Refugios,” by J. Rivera, 2020, Planes y Protocolos de emergencias del Departamento de Educación, (https://issuu.com/june-rivera/docs/dept._educacion_final). Copyright 2020 by Issuu.

Data Collection

Schools used as voting centers

CENTROS DE VOTACIÓN
ELECCIONES GENERALES
MARTES, 3 DE NOVIEMBRE DE 2020

COMISIÓN ESTATAL DE ELECCIONES
DE PUERTO RICO
PLANIFICACIÓN GEOELECTORAL

Rev. 2 nov 2020
11:50am

Municipio	Pre	UE	Tipo	Centro de Votación	Dirección	Colegio Regular	Colegio Añadido a Mano	Total Colegios
San Juan	001	01	Esc.	Albert Einstein	Cll Haydee Rexach, Esq. Ave. Borinquen	2	1	3
San Juan	001	02	Esc.	Abraham Lincoln	351, Calle Sol, Viejo San Juan	4	1	5
San Juan	001	03	Esc.	Dr. José Celso Barbosa	Parada 4 1/2, Ave Ponce de León, Viejo San Juan	4	1	5
San Juan	001	04	Col.	San Juan Bosco	Cll. Constitución, Sect. Cantera	2	1	3
San Juan	001	05	Acad.	Perpetuo Socorro	707 Cll. José Martí, Sect. Miramar, Bo. Santurce	7	1	8
San Juan	001	06	Esc.	Julián E. Blanco	Cll. Martín Travieso Esq. Cll. Estrella, San Juan	3	1	4
San Juan	001	07	Col.	Saint John's School	1454 Ave. Dr. Ashford, Condado	8	1	9
San Juan	001	08	Esc.	Ernesto Ramos Antonini	Ave. Borinquen, Sect. Barrio Obrero, Bo. Santurce	4	1	5
San Juan	001	09	Univ.	Sagrado Corazón	Cll. Rosales Pda. 26, Bo. Santurce	4	1	5
San Juan	001	10	Esc.	Alejandro Tapia y Rivera	369 Cll. Bellevue, Villa Palmeras	5	1	6
San Juan	001	11	Esc.	Federico Asenjo	Ave. Borinquen 2017, Sect. Barrio Obrero	3	1	4
San Juan	001	12	Esc.	Rafael Cordero	Cll. Hoare, Esq. Cll. Aurora, Santurce	2	1	3
San Juan	001	13	Esc.	Rafael María de Labra	Ave. Ponce de León, Pda. 18, Esq. Cll. Roberto H. Todd	3	1	4
San Juan	001	14	Acad.	San Jorge	1701 Cll. Colón, Santurce	5	1	6
San Juan	001	15	Esc.	República del Perú	Cll. Loíza Final, Bo. Santurce	5	1	6
San Juan	001	16	Esc.	Luis Rodríguez Cabrero	Cll. Marina, Res. Luis Llorens Torres	3	1	4

From "Centros de Votación," by Comisión Estatal de Elecciones de Puerto Rico, 2020, Comisión Estatal de Elecciones de Puerto Rico, (https://ceepur.org/Elecciones/docs/centrosvotacion.pdf). Copyright 2020 by Comisión Estatal de Elecciones de Puerto Rico.

Data Collection

PRSN Tsunami datasets

TsunamiReady®

GIS Data Download

The following datasets are available to download as a convenience to user on GEODATABASE (ESRI) and Raster GeoTIFF format. These datasets are distributed as they are in our web map application. Even when the data base is regularly updated, some datasets may not be up to date.

Database and Products

- Tsunami evacuation zone Puerto Rico
- Tsunami evacuation zone Virgin Island
- Tsunami flood zones (2012, 2003)
- Emergency outdoor sirens
- Assembly Points, TsunamiReady Signs, and Evacuation Routes
- Pedestrian Analysis
- PRTMAPTool WMS ArcGIS Layerfile
- ArcGIS User Manual (Spanish)

From "GIS Data Download", by Puerto Rico Seismic Network, University of Puerto Rico Mayagüez, n.d., Tsunami Program, (http://redsismica.uprm.edu/English/tsunami/tsunamiprogram/prc/gisdataenglish.php). In the public domain.

Data Collection

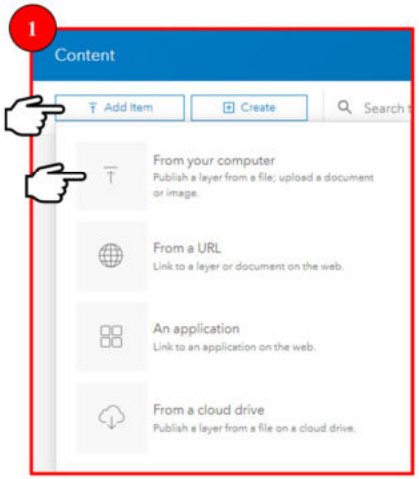
PRSN Tsunami Evacuation Maps

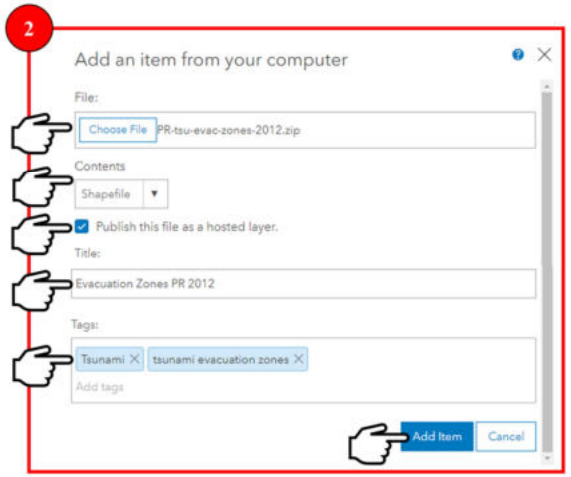
From "Puerto Rico Tsunami Program Map Tool", by Puerto Rico Seismic Network, University of Puerto Rico Mayagüez, n.d., Tsunami Program, (http://prddst.uprm.edu/apps/prtmp/). In the public domain.

From "Puerto Rico Evacuation Maps", by Puerto Rico Seismic Network, University of Puerto Rico Mayagüez, 2014, Tsunami Program, (http://redsismica.uprm.edu/English/tsunami/tsunamiprogram/prc/maps/all.php). In the public domain.

Data Processing

ArcGIS Online

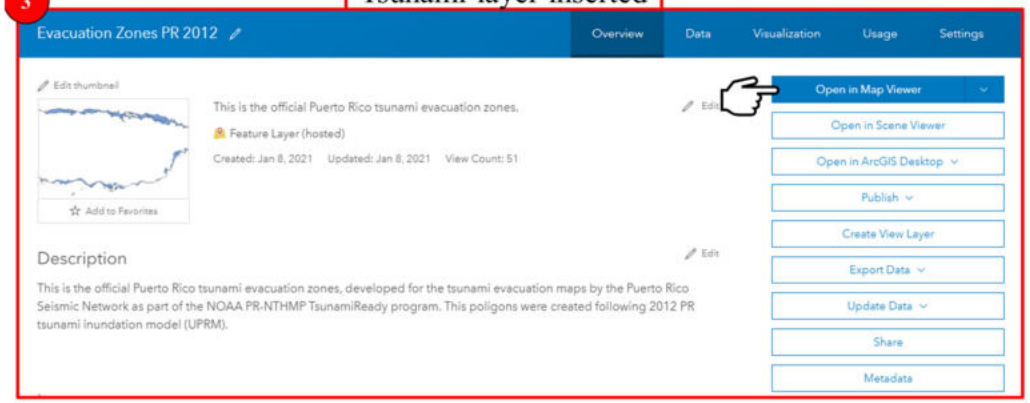




Data Processing

3

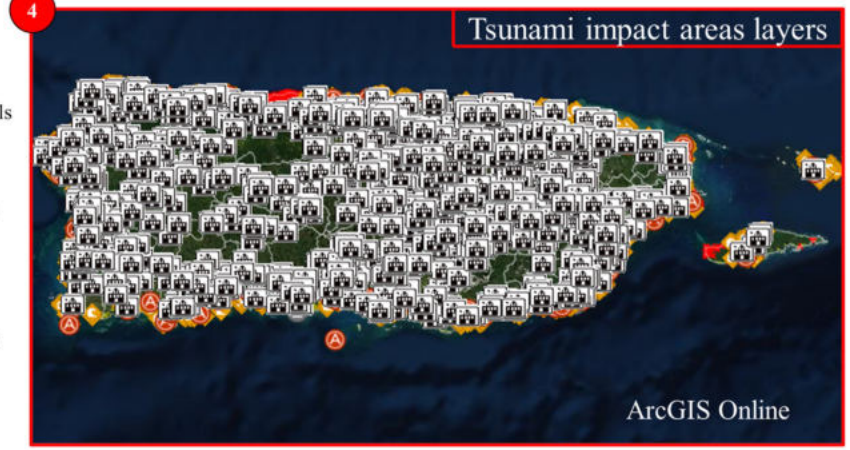
Tsunami layer inserted



Data Processing

4

Tsunami impact areas layers



Data Processing

For the purpose of this study, the tsunami evacuation zone was considered as equivalent to a tsunami hazard zone

Findings

All in the tsunami area

46 coastal municipalities

Municipality	Researchers' accessibility (km)			5 Schools	6 Voting Center	7 Shelter	8 Population
	Verónica	Joel	Average				
Aguada	170.0	155	162.5	3	1	0	1,457
Aguadilla	153.0	146	149.5	3	1	0	519
Añasco	171.0	163	167	1	0	0	0
Arecibo	98.4	95.6	97	1	0	0	97
Arroyo	45.8	93.5	69.65	0	0	0	0
Barceloneta	75.5	72.7	74.1	0	0	0	0
Bayamón	32.2	33.4	32.8	0	0	0	0
Cabo Rojo	161.0	182	171.5	3	1	0	931
Camuy	112.0	112	112	1	1	0	0
Canóvanas	33.2	9.9	21.55	0	0	0	0
Carolina	25.4	0	12.7	2	0	0	0
Cataño	**34.6**	**27.5**	**31.05**	**4**	**2**	**0**	**1,465**
Ceiba	49.7	49	49.35	0	0	0	0
Culebra	107.0	94.7	100.85	1	1	1	190
Dorado	48.3	42.9	45.6	1	0	1	937
Fajardo	55.5	41.8	48.65	0	0	0	0
Guánica	128.0	154	141	0	0	0	0
Guayama	59.5	86.5	73	1	0	0	115

← Students and teachers

Findings

Municipality	Researchers' accessibility (km)			Schools	Voting Center	Shelter	Population
	Verónica	Joel	Average				
Guayanilla	110.0	137	123.5	0	0	0	0
Guaynabo	17.5	16.2	16.85	0	0	0	0
Hatillo	110.0	105	107.5	1	0	0	0
Humacao	28.7	45.5	37.1	1	1	0	386
Isabela	137.0	130	133.5	0	0	0	0
Juana Díaz	75.9	103	89.45	2	1	0	529
Lajas	144.0	171	157.5	1	0	0	108
Loíza	**41.8**	**20.7**	**31.25**	**8**	**4**	**3**	**2,401**
Luquillo	54.0	32.5	43.25	3	1	0	596
Manatí	71.0	65.5	68.25	0	0	0	0
Maunabo	45.0	70.6	57.8	0	0	0	0
Mayagüez	**161.0**	**168**	**164.5**	**9**	**5**	**1**	**3,247**
Naguabo	36.4	61.8	49.1	0	0	0	0
Patillas	44.5	69.8	57.15	0	0	0	0
Peñuelas	108.0	135	121.5	1	0	0	245
Ponce	**87.2**	**114**	**100.6**	**4**	**2**	**0**	**1,577**
Quebradillas	124.0	119	121.5	0	0	0	0
Rincón	169.0	162	165.5	1	0	0	183

Findings

Municipality	Researchers' accessibility (km)			Schools	Voting Center	Shelter	Population
	Verónica	Joel	Average				
Río Grande	37.8	20.9	29.35	0	0	0	0
Salinas	**49.7**	**72.3**	**61**	**4**	**3**	**0**	**541**
San Juan	**32.9**	**20.4**	**26.65**	**9**	**5**	**0**	**2,083**
Santa Isabel	65.7	92.7	79.2	1	1	1	486
Toa Baja	**48.8**	**41.7**	**45.25**	**8**	**4**	**2**	**2,802**
Vega Alta	53.9	48.5	51.2	0	0	0	0
Vega Baja	63.0	60.3	61.65	0	0	0	0
Vieques	91.0	111	101	0	0	0	0
Yabucoa	36.0	61.3	48.65	0	0	0	0
Yauco	117.0	144	130.5	0	0	0	0
Total				**74**	**34**	**9**	**20,895**

Municipalities with no schools in tsunami hazard zone
Municipalities with 1 to 3 schools in a tsunami hazard zone
Municipalities with 4 to more schools in a tsunami hazard zone
Total results

25/46 coastal municipalities with schools in tsunami hazard zones

Findings Summary

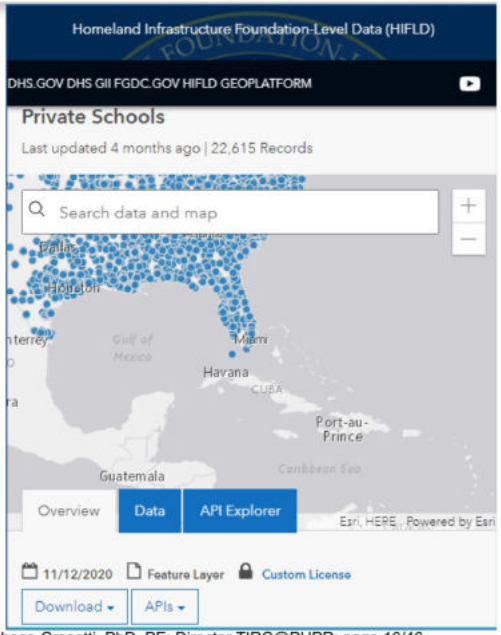
Public schools in tsunami hazard zones (THZ)

- **Total municipalities evaluated** **46**
- **Municipalities with schools in THZ** **25**
- **Schools** **74**
- **Students and Teachers Population ≈** **21,000**
- **Used as voting centers** **32**
- **Used as shelters** **10**

(2016 schools' data)

Problems Encountered

- Lack of data for private schools in PR



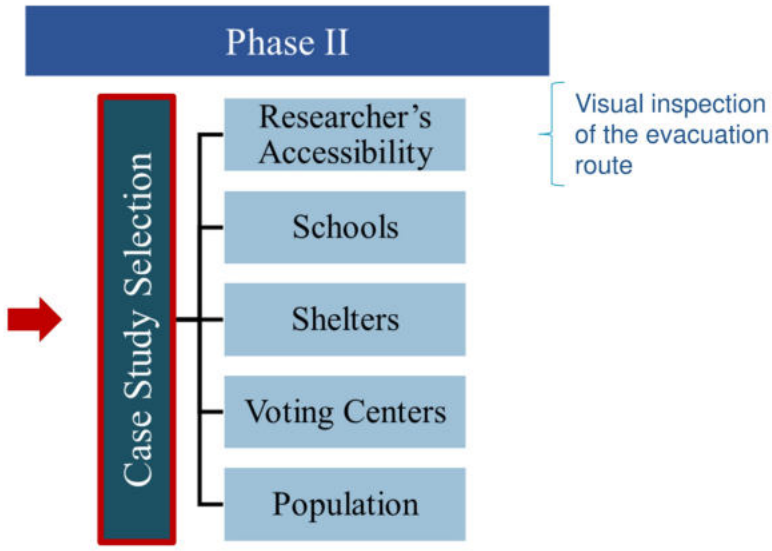
From "Private Schools," by Homeland Infrastructure Foundation-Level Data, 2020, Homeland Infrastructure Foundation-Level Data, (https://hifld-geoplatform.opendata.arcgis.com/datasets/private-schools?geometry=-140.782%2C14.067%2C-23.624%2C40.959). Copyright 2017 by U.S. Department of Homeland Security.

Problems Encountered

- Physical Addresses of private schools do not coincide with map/physical location
- This first stage considers only public schools

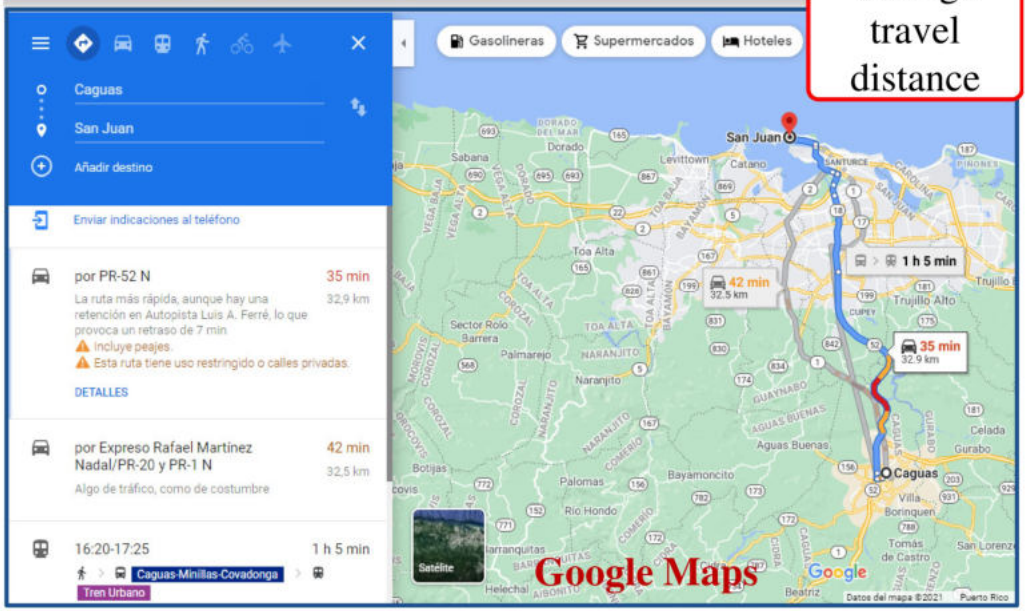
From "Directorio de Escuelas Privadas K-12 con Matrícula por Grado, Puerto Rico," by Instituto de Estadísticas de Puerto Rico, 2019, Instituto de Estadísticas de Puerto Rico, (https://datos.estadisticas.pr/dataset/directorio-de-escuelas-privadas-k-12-con-matricula-por-grado-puerto-rico). In the public domain.

Methodology – Phase II Case Study

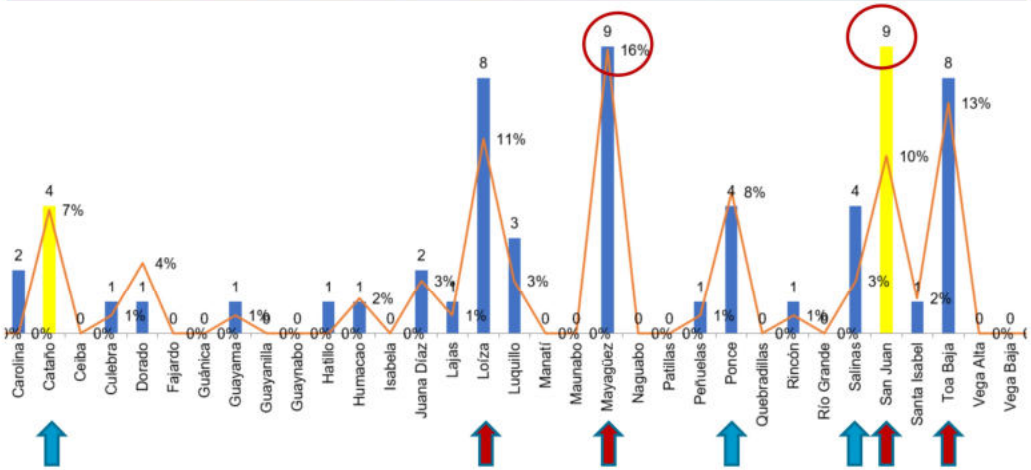


Students Accessibility

Research students average travel distance



Case Study Selection



25 municipalities
7 with 4 or more schools
4 with 8 or more schools

Significance in number of schools and population
Additional use as shelters and voting centers
Accessibility for visual inspection

Case Study Selection

Critical Municipalities 7/25

Municipality	Schools in Tsunami Hazard Zone	Voting Center	Shelter	Population
Cataño	4	2	0	1,465
Loíza	8	4	3	2,401
Mayagüez	9	5	1	3,247
Ponce	4	2	0	1,577
Salinas	4	3	0	541
San Juan	9	5	0	2,083
Toa Baja	8	4	2	2,802
Total	**46**	**25**	**6**	**14,116**
	62%	74%	67%	68%

About 70% in all indicators

Should be considered next

Two additional critical cases were also evaluated (one in Loiza and one in Toa Baja)

Case Study Selection

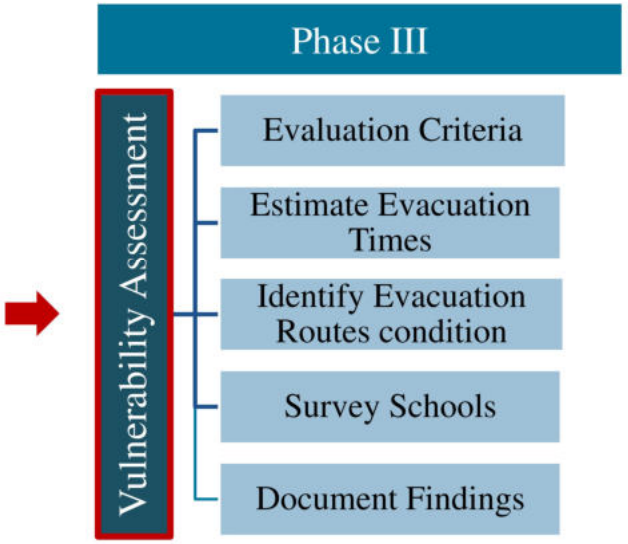
Cataño	
Researcher's Accessibility	31.05 km
Schools	4
Students	1367
Teachers	98
Population	1465
Voting Center	2
Refuge	0

Case Study Selection

San Juan	
Researcher's Accessibility	26.65 km
Schools	9
Students	1920
Teachers	163
Population	2083
Voting Center	5
Refuge	0

	Schools in Tsunami Hazard Zone	Voting Center	Shelter	Population
Case study vs Critical	28%	28%	0%	25%

Methodology – Phase III Vulnerability Assessment



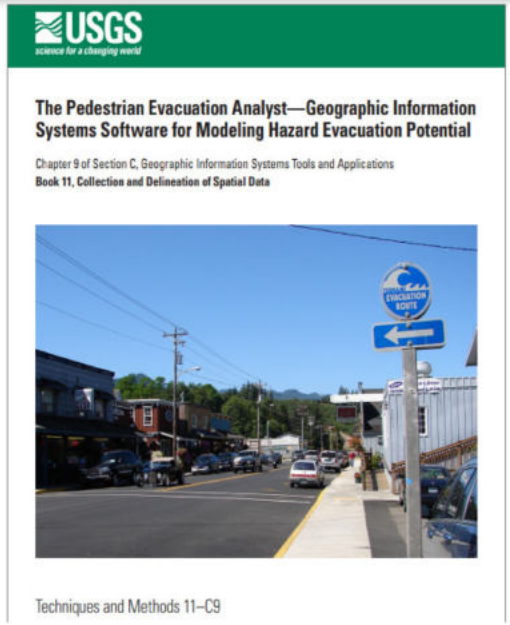
Select Evaluation Criteria

- Primary factor for vulnerability assessment
  - Evacuation time from the school to safety area
    - Type of analyses / times estimated:
      - From the internal assembly area to the external assembly area
      - From the internal assembly area to the exit point of the tsunami evacuation zone
    - Principal tasks
      - Identify internal and external assembly area
      - Identify route
      - Plot the route and estimate travel time
      - Evaluate alternate routes in case of after earthquakes hazards

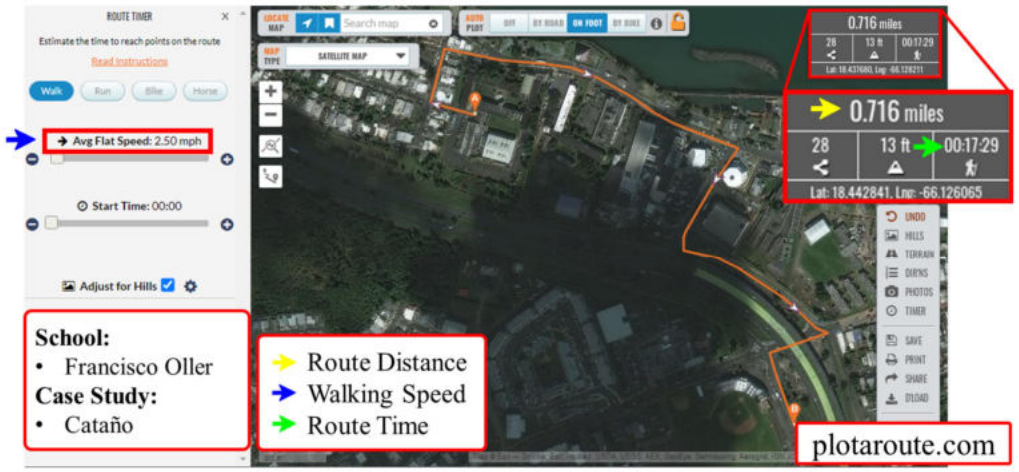
Evacuation Times

Walking Speed Type	Walking Speed Value (mph)
Slow Walk	2.46
Moderate Walk	2.70
Fast Walk	3.40
Average Walk	2.50

From "The pedestrian evacuation analyst: Geographic information systems software for modeling hazard evacuation potential" by J. M. Jones, P. Ng, and N. J. Wood, 2014, Collection and delineation of spatial data, (https://doi.org/10.3133/tm11C9). Copyright 2014 by U.S. Geological Survey.



Evacuation Times



Plotaroute GIS web tool

Evacuation Times

Figure 6-193 Evacuation Route until Leaving the Hazard Zone for Francisco Oller School (Google Earth – 2016)

Evacuation Times

Figure 6-194 Evacuation Route until Reaching the Assembly Place for Francisco Oller School (Google Earth – 2016)

Select Evaluation Criteria

- Complementary factors for vulnerability assessment
  - Condition of the evacuation route
    - Field visit/visual inspection
    - Virtual tour/visual inspection ⟸

Walkway Conditions

- Virtual tour visit to assess if the route
  - Avoids possible after earthquake obstructions
    - Such as bridges or electric lines that may collapse
  - Has adequate effective width and does not present obstacles to the pedestrian flow
    - Such as urban furniture
- Also comment on the pathway
  - Avoids walking parallel to the sea
  - Moves away from the coastline in the shortest time
  - Presence of other heavy pedestrian flow generators

Walkways Conditions

Street view capability

Google Earth Pro GIS tool

Select Evaluation Criteria

- Complementary factors for vulnerability assessment
  - Survey schools' preparation and relevant data
    - Develop a data collection form
    - Contact schools to ask for collaboration
    - Send web form
    - Process results

Schools Survey

- Not individualized, but organized by municipality
- Google Forms

Vulnerabilidad de las Escuelas en Puerto Rico ante Eventos de Tsunami

Este formulario fue creado para el proyecto de investigación titulado "La Vulnerabilidad de las Escuelas en Puerto Rico ante Eventos de Tsunami" de la Universidad Politécnica de Puerto Rico. El estudio tiene como objetivo hacer un análisis de la vulnerabilidad de las escuelas, identificando aquellas que están en zonas de evacuación de tsunami, las trayectorias de desalojo, la condición de estas rutas y otros factores que puedan impactar al tiempo de evacuación. Atendiendo a estos objetivos, el propósito de este formulario es recopilar datos relevantes de las escuelas públicas que se encuentran en zona de evacuación de tsunami. Estos datos se utilizarán con objetivos estrictamente académicos.

El plan de evacuación o desalojo en caso de tsunamis se ha dividido en dos etapas. La primera etapa corresponde al proceso de reunir a todo el plantel escolar en un lugar de asamblea interno de la escuela, luego de que suene la alarma de tsunami. La segunda etapa comprende los procedimientos de movilización peatonal de todo el plantel escolar desde el lugar de asamblea interno hasta el lugar de asamblea externo fuera de la zona de evacuación de tsunamis, en el caso de una evacuación horizontal. Esta segunda etapa también podría consistir en una evacuación vertical a pisos elevados de edificaciones apropiadas.

Esperamos que este estudio pueda contribuir en identificar áreas de oportunidad para mejorar los procesos de evacuación y proponer alternativas para ello.

Schools Survey

* Required

Municipio *
- Cataño
- San Juan

Indique el nivel educativo de escuela. (Seleccione todos los que apliquen). *
- Escuela Primaria
- Escuela Secundaria
- Escuela Superior

¿Cuándo se construyó su escuela? *
- Antes del 1987
- Después del 1987

Built year

¿Ha sido orientado sobre el peligro de tsunami para su escuela? *
- Sí
- No

¿Ha recibido algún entrenamiento o conferencia sobre preparación ante el posible impacto de un tsunami en su escuela? *
- Sí
- No

¿Su escuela tiene un plan de evacuación de tsunami? *
- Sí
- No

Tsunami evacuation plan

¿Ha sido claramente audible el sistema de alarmas de tsunami en su escuela? *
- Sí
- No

¿Tiene algún estudiante con impedimento físico? De ser así, ¿ha desarrollado planes especiales de evacuación para esta población? *

Special needs

- Sí hay estudiantes con impedimento físico en la escuela, y sí se han desarrollado procedimientos especiales de desalojo para esta población.
- Sí hay estudiantes con impedimento físico en la escuela, y no se han desarrollado procedimientos especiales de desalojo para esta población.
- No hay estudiantes con impedimento físico en la escuela, y sí se han desarrollado procedimientos especiales de desalojo para esta población.
- No hay estudiantes con impedimento físico en la escuela, y no se han desarrollado procedimientos especiales de desalojo para esta población.

¿Ha practicado la primera etapa del plan de evacuación de tsunami en su escuela? (Simulacro movilizando todo el plantel escolar hasta el lugar de asamblea interno). *
- Sí
- No

Tsunami evacuation drills

Schools Survey

Indique con qué frecuencia ha practicado esta primera etapa del plan de evacuación en su escuela (Simulacro). *
- Nunca se ha practicado
- Una vez cada dos años
- Una vez al año
- Dos veces al año
- Other:

¿Cuál es el nombre del lugar de asamblea interno, indicado para su escuela? (El nombre de la zona segura o punto de reunión dentro de la escuela al cual ir en caso de una alarma de tsunami, como primera etapa del plan de desalojo). De no tener un plan de evacuación, responda N/A.

Internal Assembly Place IAP

Si ha practicado el plan de desalojo, ¿cuál ha sido el tiempo total en esta primera etapa en minutos? (El tiempo transcurrido desde que suena la alarma de aviso de tsunami hasta que toda la población escolar llega al lugar de asamblea interno). De no haber practicado un plan de evacuación, responda 0. *

Evacuation times from Classroom to IAP

¿Cuál es el nombre del lugar de asamblea externo indicado para su escuela? (El nombre de la zona segura o punto de reunión fuera de la escuela, y fuera de la zona de peligro de tsunami, al cual ir en caso de alarma de tsunami, en la segunda etapa del plan de desalojo). De no tener o conocer un lugar de asamblea indicado en el plan de evacuación, responda Desconozco. *

External Assembly Place EAP

¿Ha practicado la segunda etapa del plan de evacuación de tsunami en su escuela? (Simulacro caminando con todo el plantel escolar hasta el lugar de asamblea externo). *
- Sí
- No

Indique con qué frecuencia ha practicado esta segunda etapa del plan de evacuación en su escuela (simulacro). *
- Nunca se ha practicado
- Una vez cada dos años
- Una vez al año
- Dos veces al año
- Other:

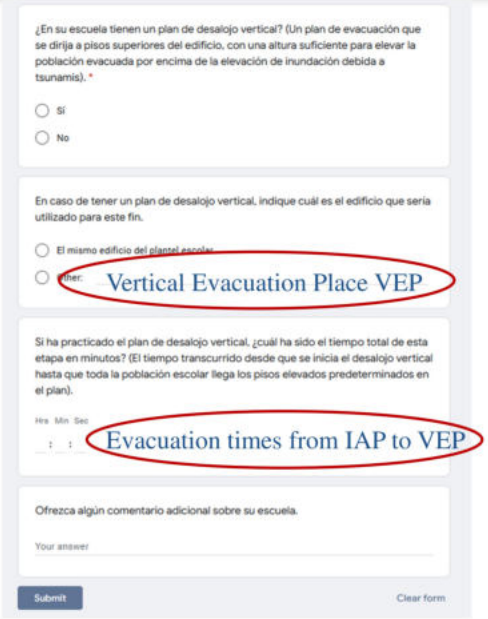
Si ha practicado el plan de desalojo, ¿cuál ha sido el tiempo total de esta segunda etapa en minutos? (El tiempo transcurrido desde que suena la alarma de inicia el desalojo hasta que toda la población escolar llega al lugar de asamblea externo). De no haber practicado un plan de evacuación, responda 0. *

Evacuation times from IAP to EAP

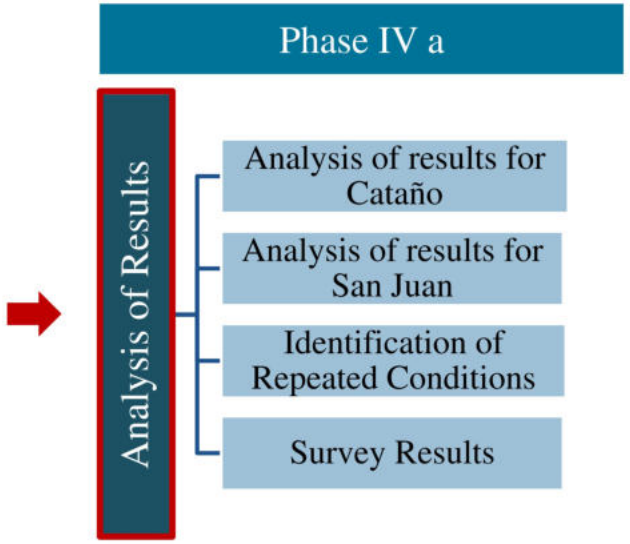
¿En su escuela tienen un plan de desalojo vertical? (Un plan de evacuación que se dirija a pisos superiores del edificio, con una altura suficiente para elevar la población evacuada por encima de la elevación de inundación debida a tsunamis). *
- Sí
- No

Vertical Evacuation (VE)

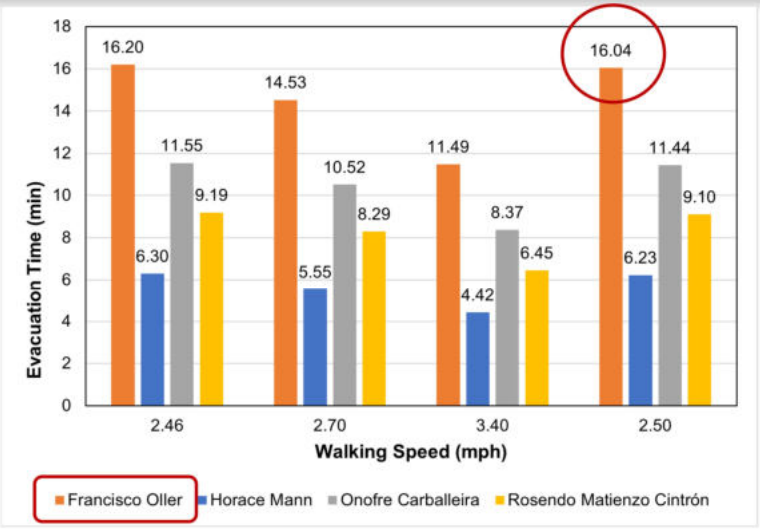
Schools Survey



Methodology – Phase IV a
Analysis of Results



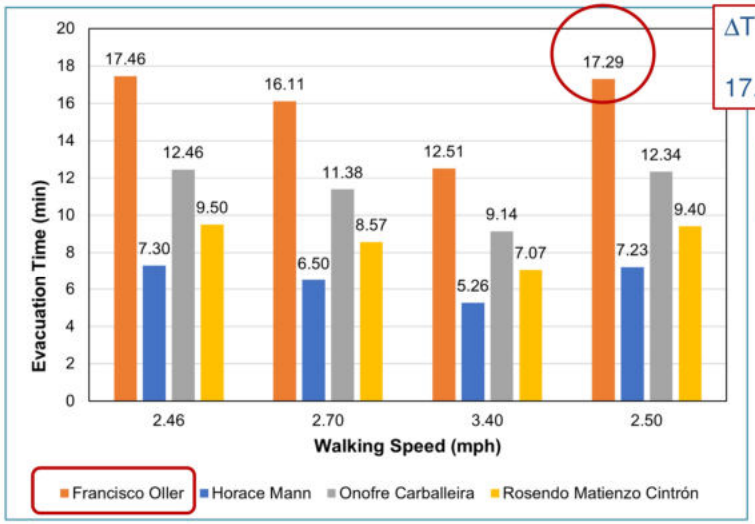
Analysis of Results - Cataño



Range
6 – 16 m

Evacuation time until leaving the hazard zone

Analysis of Results - Cataño



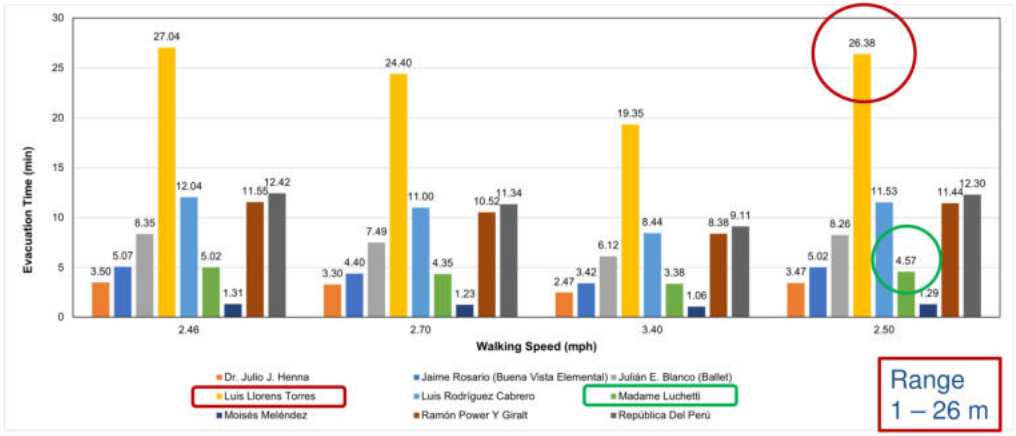
ΔT = 1.25 m

17.29 - 16.04

Range
7 – 17 m

Evacuation time until reaching the assembly place

Analysis of Results – San Juan



Range
1 – 26 m

Evacuation time until leaving the hazard zone

Analysis of Results – San Juan

Total evacuation time until reaching external assembly place may mislead planning analysis and assessment of critical schools

ΔT = 44.94 m

49.51 – 4.57

Range
9 – 49 m

Evacuation time until reaching the assembly place

Analysis of Results – Alternate Routes

Municipality	School	Minimum Evacuation Route	Alternate Evacuation Routes				Difference between times			
			1	2	3	4	1	2	3	4
Cataño	Francisco Oller	00:17:29	00:19:35	00:35:22			00:02:06	00:17:53		
	Horace Mann	00:07:23	00:09:03	00:08:17			00:01:40	00:00:54		
	Onofre Carballeira	00:12:34	00:15:33	00:35:59			00:02:59	00:23:25		
	Rosendo Matienzo Cintrón	00:09:40	00:10:13	00:11:01	00:41:33		00:00:33	00:01:21	00:31:53	
San Juan	Dr. Julio J. Henna	00:17:00	00:18:23	00:18:33	00:49:57		00:01:23	00:01:33	00:32:57	
	Jaime Rosario	00:17:02	00:17:43	00:23:31	00:42:28		00:00:41	00:06:29	00:25:26	
	Julián E. Blanco	00:40:02	00:40:36	00:42:45			00:00:34	00:02:43		
	Luis Llorens Torres	00:33:35	00:37:58	00:37:00	01:06:34		00:04:23	00:03:25	00:32:59	
	Luis Rodríguez Cabrero	00:24:55	00:29:41	00:27:14	00:57:24		00:04:46	00:02:19	00:32:29	
	Madame Luchetti	00:49:51	00:55:46	00:56:21	01:14:12		00:05:55	00:06:30	00:24:21	
	Moisés Meléndez	00:09:25	00:10:25	00:11:03	00:29:02	00:33:12	00:01:00	00:01:38	00:19:37	00:23:47
	Ramón Power Y Giralt	00:25:47	00:30:31	00:26:53			00:04:44	00:01:06		
	República Del Perú	00:29:04	00:31:38	00:30:05			00:02:34	00:01:01		

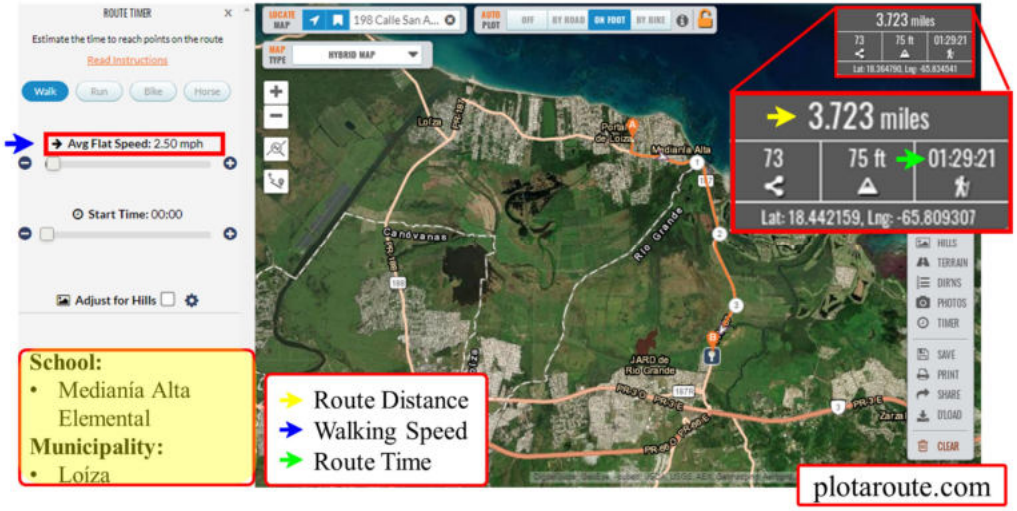
2 to 4 alternative evacuation routes for each school

Increase in evacuation time between 2 and 30 minutes

Possible impact of encountering obstacles when evacuating

Analysis of Results – Other Critical Cases

Route to Get Out of the Tsunami Hazard Zone

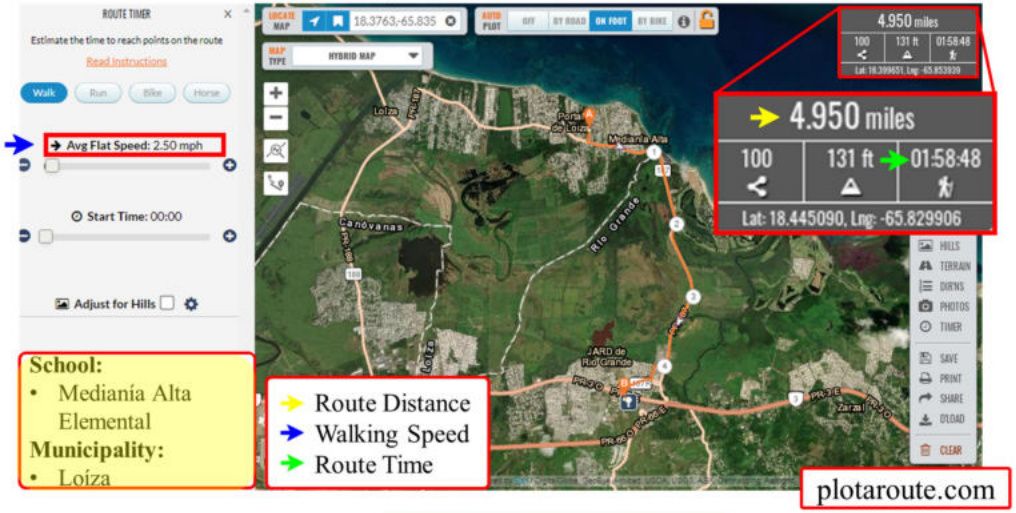


PR-187

1h 29m, 3.72 miles !!!

Analysis of Results – Other Critical Cases

Route to Get to the Assembly Place



School:
- Mediania Alta Elemental

Municipality:
- Loíza

PR-187

1h 59m, 4.95 miles !!!

Analysis of Results – Other Critical Cases

Evacuation Times Summary

Mediania Alta Elemental School

Walking Speed USGS (mph)	Evacuation Time - PlotARoute (hr:min:sec)	
	Route to Get to the Assembly Place	Route to Get Out of the Tsunami Hazard Zone
2.46	2:00:44	01:30:48
2.70	1:50:00	01:22:44
3.40	1:27:21	01:05:42
2.50	1:58:48	01:29:21
Distance (miles)	4.950	3.723

Analysis of Results – Other Critical Cases

Route to Get Out of the Tsunami Hazard Zone

School:
- Academia Espíritu Santo Levittown

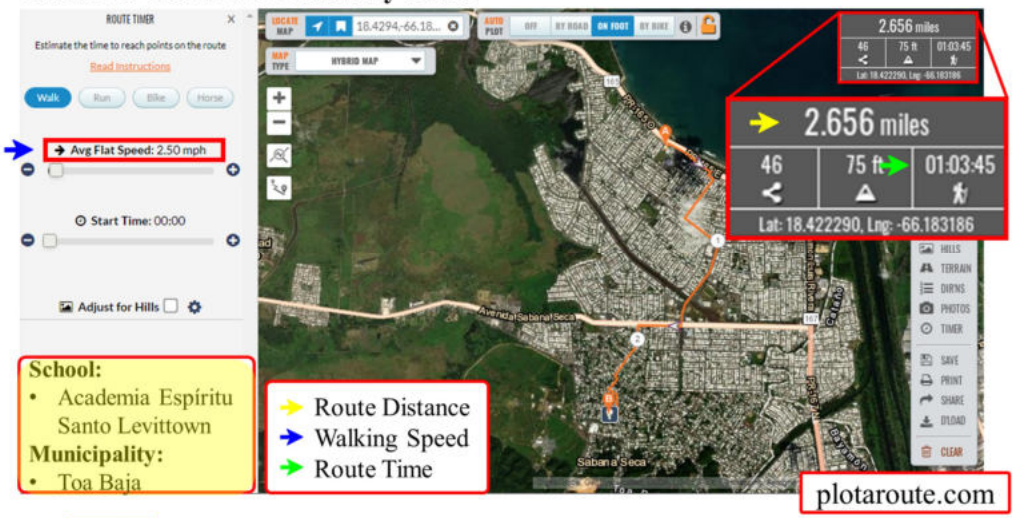
Municipality:
- Toa Baja

PR-165
PR-866

51m, 2.12 miles !!!

Analysis of Results – Other Critical Cases

Route to Get to the Assembly Place



School:
- Academia Espíritu Santo Levittown

Municipality:
- Toa Baja

PR-165
PR-866

1h 4m, 2.66 miles !!!

Analysis of Results – Other Critical Cases

Evacuation Times Summary

Academia Espíritu Santo Levittown

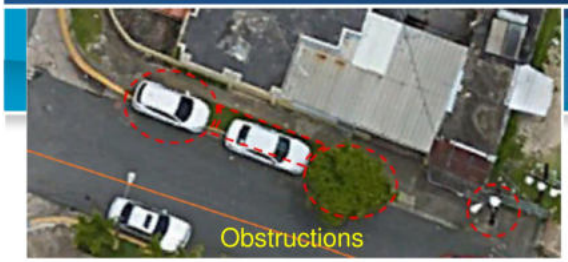
Walking Speed USGS (mph)	Evacuation Time - PlotARoute (hr:min:sec)	
	Route to Get to the Assembly Place	Route to Get Out of the Tsunami Hazard Zone
2.46	01:04:34	00:51:37
2.70	00:58:49	00:47:02
3.40	00:46:43	00:37:21
2.50	01:03:45	00:50:54
Distance (miles)	2.656	2.121

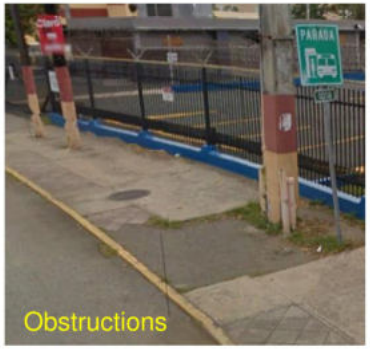
Virtual Tour Results - Cataño

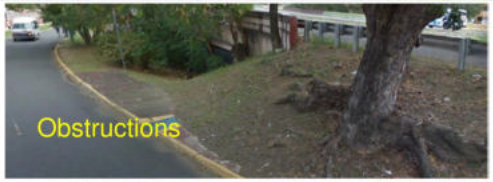
The Francisco Oller school pedestrian route

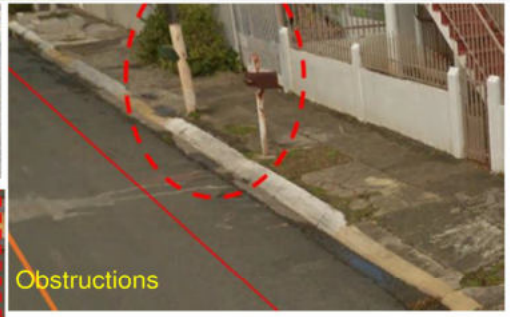
- 46% of the route parallel to the sea
- Signs that indicate the evacuation route
- Crosses below a bridge
- Electric power lines
- Obstructions by vehicles, urban mobiliary
- Damages and discontinuities

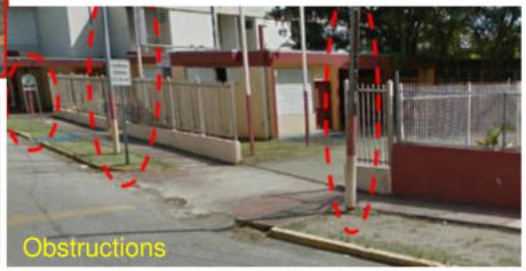
qualitative

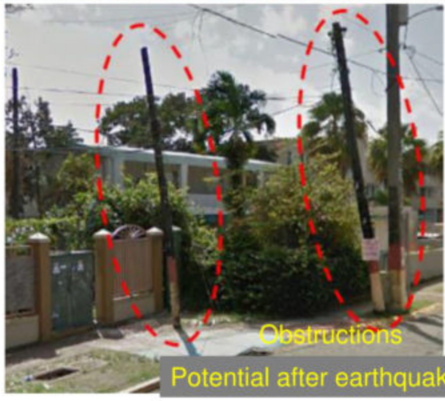










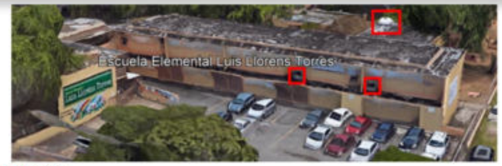


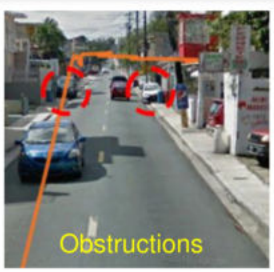
Virtual Tour Results – San Juan

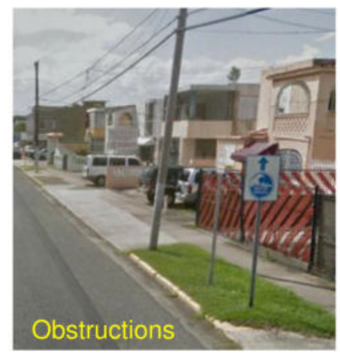
Luis Llorens Torres school pedestrian route

- 62% of the route parallel to the shoreline
- Signs on the road.
- Crosses under a bridge
- Obstructions by vehicles, street furniture
- Damage and discontinuities

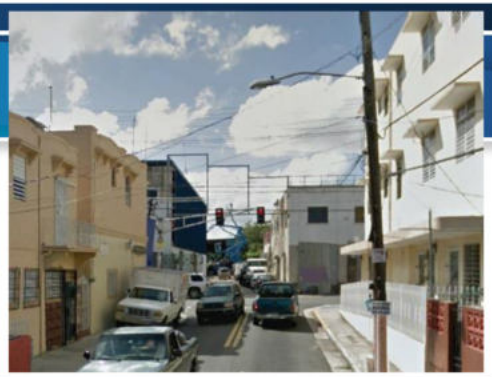
} qualitative







Potential after earthquake hazard - bridge



Potential after earthquake hazard – electric power lines

Schools Survey Results

Table 6-29 Form Results for Schools in Google Form

	Question	Answer			
1	Municipality	Cataño		San Juan	
		50%		50%	
2	Indicate the educational level of the school	Primary school		Secondary school	High school
		50%		0%	50%
3	When was your school built?	Before 1987		After 1987	
		100%		0%	
4	Have you been oriented about the tsunami hazard for your school?	Yes		No	
		100%		0%	
5	Have you received any training or lectures on tsunami preparedness at your school?	Yes		No	
		100%		0%	
6	Does your school have a tsunami evacuation plan?	Yes		No	
		100%		0%	
7	Has the tsunami warning system at your school been clearly audible?	Yes		No	
		50%		50%	
8	Do you have a student with a physical disability? If so, have you developed special evacuation plans for this population?				
9	There are students with physical disabilities in the school, and special evacuation procedures have been developed for this population.	There are students with physical disabilities in the school, and no special evacuation procedures have been developed for this population.		There are no students with physical disabilities in the school, and special evacuation procedures have been developed for this population.	There are no students with physical disabilities in the school, and no special evacuation procedures have been developed for this population.
	0%	0%		50%	50%

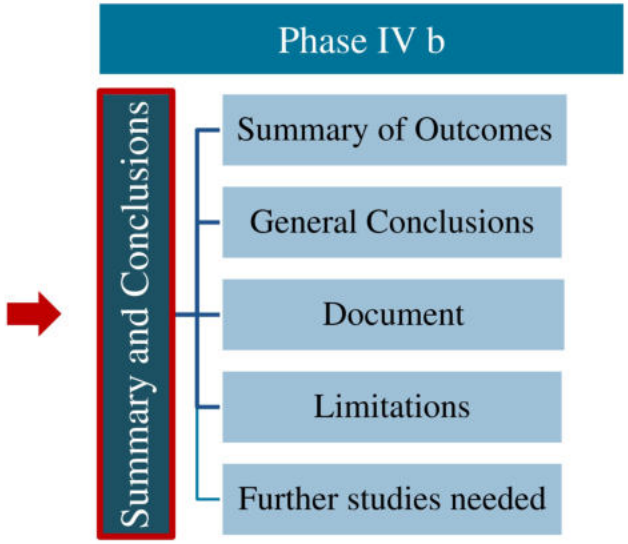
Schools Survey Results

10	Have you practiced the first stage of the tsunami evacuation plan at your school?	Yes		No	
		100%		0%	
11	Please indicate how often you have practiced this first stage of the evacuation plan at your school (Drill).	It has never been practiced	Once every two years	Once a year	Twice a year
		0%	0%	50%	50%
12	What is the name of the internal assembly place, indicated for your school? (The name of the safe place within the school to go to in a tsunami alarm).	In the schoolyard		Backyard close to PR 5 and the third level of the school	
13	If you have practiced the evacuation plan, what was the total time in this first stage in minutes?	00:03:00		01:00:00	
14	What is the name of the outside assembly location indicated for your school? (The name of the safe zone or assembly point outside the school to go to in the event of a tsunami alarm).	"Plaza Barcelo Santurce"		"Parque Perucho Cepeda"	
15	Have you practiced the second stage of the tsunami evacuation plan at your school? (Drill walking with the school campus to the external assembly site).	Yes		No	
		100%		0%	
16	Please indicate how often you have practiced this second stage of the evacuation plan at your school (drill).	It has never been practiced	Once every two years	Once a year	Twice a year
		0%	50%	0%	50%
17	If you have practiced the evacuation plan, what was the total time for this second stage in minutes?	00:08:00		01:00:00	
18	Does your school have a vertical evacuation plan? (An evacuation plan targeting upper floors of the building, high enough to raise the evacuated population above the tsunami flood elevation.)	Yes		No	
		50%		50%	
19	If you have a vertical evacuation plan, indicate which building would be used for this purpose.	The same building as the school campus		Other	
		100%		0%	
20	If you have practiced the vertical evacuation plan, what was the total time for this stage in minutes?	00:02:30		00:45:00	

Schools Survey Results

- Both schools
  - Show a varied age range due to their educational level.
  - Were built before 1987.
  - Have tsunami evacuation plans.
- The evacuation times
  - For the Cataño school was comparable to those obtained in Phase III
  - For San Juan was comparable to the ones obtained in the analyses, but the similarity between two phases could indicate the information was not accurate.

Methodology – Phase IV b
Summary and Conclusions



Summary

- The project has assessed for all Puerto Rico
  - The public schools in tsunami hazard (evacuation) zones
  - Their usage as voting centers and shelters
  - The student and faculty population potentially affected

Summary

- The project has assessed for each public school in Cataño and San Juan Municipalities
  - The evacuation time
    - From the internal assembly place to exiting the tsunami evacuation area
    - From the internal assembly place to the external assembly area
  - The conditions of the walkway in terms of obstacles, hazards, and pathway for the critical school in each municipality

General Conclusions

- Schools with the longest times to leave the tsunami hazard zone are critical and more vulnerable to a tsunami event
  - May be used as one of the planning criteria for prioritize rehabilitation funds, and evaluate vertical evacuation needs
- Schools in San Juan are more vulnerable than schools in Cataño
- There are other municipalities with more vulnerable conditions
  - Case of Loiza and case of Toa Baja

General Conclusions

- The characteristics of the evacuation routes evaluated using Google Earth Pro for the two most critical schools showed
  - They may not be suitable for transit during the evacuation process due to the presence of obstacles, hazards, and routes parallel to the coastline
  - An improvement of pedestrian facilities used as evacuation routes could be advisable
  - The use of vehicular roads as evacuation facilities (an its implications) should be considered

General Conclusions

- Google Earth Pro in conjunction with ArcGIS and PlotARoute are useful tools to perform the analysis and evaluation of the conditions of the characteristics of schools' evacuation routes
- The results of the survey forms
  - Validate the established assumption regarding the assembly places
  - Showed that both schools were pre-code (1987)
  - Two responses are not significative
  - Challenges
    - Get schools to participate in the survey
    - Validate responses

General Conclusions

- The evacuation times are useful to have an idea, but are considered lower bound estimate
  - They consider only one stage of the evacuation process, not the complete evacuation process timeline
  - The particular conditions of the evacuation route, traffic, and other characteristics are not factored in
  - Other studies showed different (and lower) average evacuation speeds, and variations with age

Average walking speed in the 1993 Japan tsunami					
Age / Average Speed	20-29	30-39	40-49	50-59	60 and older
[m/s]	0.87	1.47	1.03	0.68	0.58
[Km/h]	3.13	5.29	3.71	2.45	2.09
[mph]	1.95	3.29	2.30	1.52	1.30

From "Preparing for Community Tsunami Evacuations: From inundation to evacuation maps, response plans and exercises", by UNESCO/IOC, 2020, Manuals and Guides, 82 (Suppl. 1), (https://reliefweb.int/sites/reliefweb.int/files/resources/373019eng.pdf). Copyright 2020 by UNESCO.

Documentation

The project has been documented and disseminated

- Technical report
  - 388 pp
- Poster

http://prcrepository.org:8080/xmlui/handle/20.500.12475/1166

Documentation

Report Sample Pages

Figure 5-64 Schools located in tsunami hazard zone in Loiza

Figure 5-65 Schools located in tsunami hazard zone in Loiza [Zoom]

The total population that could be affected by the impact of a tsunami in the municipality of Loiza is 2,401 people. Of the total of 8 schools that are in the tsunami danger zone, 4 are used as a voting center and 3 as a refuge. Schools located in tsunami hazard zones are shown in Table 5-16.

Table 5-16 Summary of schools in tsunami hazard in Loiza

Schools	Students	Teachers	Population	Voting Center	Refuge
Belén Blanco de Zeguerra	174	14	192	Yes	No
Carlos Escobar López	191	19	210	No	Yes
Celso González Vaillant	323	26	349	No	Yes

Emiliano Figueroa Torres	78	8	86	No	No
Jobos	105	6	111	Yes	No
Medianía Alta Elemental	678	34	712	Yes	Yes
Nueva Superior de Loiza (Super Vocacional)	552	32	584	Yes	No
Parcelas Vieques	145	12	157	No	No
Total			2401	4	3

5.1.27 Luquillo

This municipality has 7 schools (Figure 5-66), of which 3 are in a tsunami hazard zone (Figure 5-67 and Figure 5-68). These schools are: Pablo Suarez Ortiz which is permanently closed, Rafael N. Coca with a population of 458, and Rosendo Matienzo Cintrón with a population of 138. The total school population that could be affected by a tsunami for Luquillo is 596 people. Of the total of schools, only one is used as a voting center, while none is used as a refuge. The data for these schools is summarized in Table 5-17.

Figure 5-66 Location of Schools in Luquillo

Documentation

Report Sample Pages

6.1.1.1.1 Francisco Oller

The Francisco Oller school evacuation route starts from "Calle Este" and turns onto Las Nereidas Avenue (PR-88). Then, it turns along Olivo Street, exit at the El Callo Avenue terminal of PR-165 and turns onto José Celso Barbosa Avenue (PR-5) until reaching the predetermined assembly place (Figure 6-2).

The route of this school has a distance of 0.716 miles (Figure 6-2). Figure 6-3 is zoomed in with the information obtained from "Plot a Route" for an average walking speed. Table 6-1 shows the evacuation times for the different walking speeds.

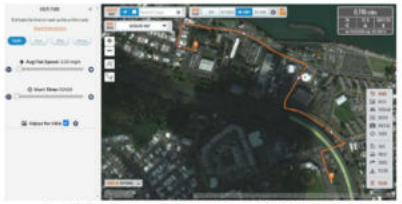


Figure 6-2 Route for Average Walking Speed of Francisco Oller School at Cataño

Figure 6-3 Evacuation Time and Route's Distance of Route for Average Walking Speed of Francisco Oller School

Table 6-1 Evacuation Time for Every Speed of Francisco Oller School at Cataño

Walking Speed (mph)	Evacuation Time (min)
2.46	17.46
2.70	16.11
3.40	12.51
2.50	17.29
Distance (miles)	0.716

6.1.1.1.2 Horace Mann

The Horace Mann school evacuation route starts from PR-875 turn slight to "Calle Barbosa" and then make a left turn until reaching the predetermined assembly place (Figure 6-4).

The route of this school has a distance of 0.301 miles (Figure 6-4). Figure 6-5 is zoomed in with the information obtained from "Plot a Route" for an average walking speed. Table 6-2 shows the evacuation times for the different walking speeds.

Figure 6-4 Route for Average Walking Speed of Horace Mann School at Cataño

Figure 6-5 Evacuation Time and Route's Distance of Route for Average Walking Speed of Horace Mann School

Documentation

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6.3 Alternate Routes

The alternate routes discussed below use the same route planner (Plot a Route) resource used in the evacuation routes section above. The alternate routes of the case study schools represent only the possible ways to get to the safe place. However, there may be several routes for each of the schools. These were not selected as a breakdown of the previous section since they present greater distances and evacuation times that would worsen the vulnerability of schools. Likewise, for this section, the routes close to the evacuation routes previously analyzed are considered because a greater route would also correspond to a greater vulnerability.

Unlike the previous evaluation, this section shows the routes on a satellite map and on a street map to better represent the crossing of each route. Also consider only the average travel speed of 2.50 mph to compare evacuation times. On the other hand, these routes use the same assembly places assumed in the previous section. But in some schools, other nearby assembly places are presented for comparison.

6.3.1 Cataño

The alternate evacuation routes of the four schools in this municipality travel from their respective origins to the same assembly place used in the previous routes. This is Perucho Cepeda Stadium.

6.3.1.1 Franciso Oller

Francisco Oller school has two other possible routes to get to the assembly site. The first alternate route close to the previously described route is shown in Figure 6-59. This route has a distance of 0.800 miles for an evacuation time of 19 minutes 35 seconds. This route has 2 minutes and 6 seconds more compared to the evacuation time of the route used for the vulnerability assessment of 17 minutes and 29 seconds (Figure 6-61).

Figure 6-59 First Alternate Route of Francisco Oller School at Cataño

Figure 6-61 Evacuation Time and Route's Distance of First Alternate Route of Francisco Oller School

Figure 6-60 Street of First Alternate Route of Francisco Oller School

Documentation

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6.4 Visit to Schools

In this evaluation, the possible characteristics of vulnerability in the schools with the highest risk are identified according to their evacuation time previously evaluated. The vulnerability characteristics considered for this are: the identification of safe zones, the evaluation of the structural conditions of the schools, and the examination of the facilities of the evacuation routes. For the municipality of Cataño, the school that takes the longest to evacuate and leave the tsunami danger zone is Francisco Oller school. While, for San Juan, the school with the longest evacuation time to reach a safe zone is Luis Llorens Torres school. This preliminary assessment is done using Google Earth and its space walk resources. This evaluation only assumes the characteristics observed through the tour in Google Earth. However, the characteristics may vary depending on the validity found in the face-to-face view of the next section.

6.4.1 Francisco Oller

The Francisco Oller school as identified in Figure 6-169 is a secondary school in the educational region of Bayamón. It is located at Las Nereidas Avenue in Cataño PR, 00962. It has a latitude of 18.4424482 and a longitude of -66.1284174 according to its coordinates.

Figure 6-169 Francisco Oller School (Google Earth – 2016)

Oller school has a total population of 723 people between 678 students and 45 teachers. It is a school used as a voting center and not as a refuge. On the other hand, it has an evacuation time from the school to the tsunami safe zone of 16 minutes 4 seconds. And an evacuation time from the school to the assembly site of 17 minutes and 29 seconds. These data or vulnerability parameters obtained in previous chapters and sections are summarized in Table 6-27. In this way, the first two columns with the number of students and teachers that could be affected by a tsunami. The third column with the amount of the total school population between students and teachers that could be affected by a possible tsunami event. The fourth and fifth column with the use or occupation of the school, whether it is a voting center or shelter. And the sixth and seventh column with the evacuation times. The sixth column with the time it takes for the population to leave the tsunami danger zone and the seventh column with the evacuation time to reach the assembly site.

Francisco Oller school has a total population of 723 people between 678 students and 45 teachers. It is a school used as a voting center and not as a refuge. On the other hand, it has an evacuation time from the school to the tsunami safe zone of 16 minutes 4 seconds. And an evacuation time from the school to the assembly site of 17 minutes and 29 seconds. These data or vulnerability parameters obtained in previous chapters and sections are summarized in Table 6-27. In this way, the first two columns with the number of students and teachers that could be affected by a tsunami. The third column with the amount of the total school population between students and teachers that could be affected by a possible tsunami event. The fourth and fifth column with the use or occupation of the school, whether it is a voting center or shelter. And the sixth and seventh column with the evacuation times for an average walking speed of 2.50 mph. The sect column with the time it takes for the population to leave the tsunami danger zone and the seventh column with the evacuation time to reach the assembly site.

Table 6-27 Summary of vulnerability parameters for Francisco Oller school

Population	Occupancy	Evacuation Time (min:sec)

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(1) Students	(2) Teachers	(3) Total Population	(4) Voting Center	(5) Refuge	(6) Tsunami Hazard Zone	Evacuation Place
678	45	723	Yes	No	16:04	17:29

6.4.1.1 Structure Caracteristics

This school covers an area of approximately 19,500 square meters according to measurements estimated in Google Earth. Figure 6-170 represents through a polygon the delimitation of said area with (a) shaded fill and (b) marked edge.

(a) (b)

Figure 6-170 Estimated Total Floor Area for Francisco Oller School (Google Earth – 2016)

Francisco Oller school has as part of its facilities a parking lot, a field and the structure with the classrooms. These facilities are assumed according to the distribution of spaces observed in Google Earth (Figure 6-169).

6.4.1.2 Plan Irregularities

Francisco Oller school has an irregularity in plan since it has a complex geometric shape. This is made up of more than one independent structural framing system divided by joints. A "box" type structure that connects to an "L" shaped structure and to two other rectangular shaped structures. This represents a risk and a seismic vulnerability of the building, since the ideal is that the geometry is a simple and redundant one, both in plan and elevation. Complex, irregular, or asymmetric shapes can cause poor behavior when the building is subjected to seismic loading. Irregular geometry allows the structure to twist or try to rotate out of order. The lack of uniformity makes it easier for some corners to have intense concentrations of force, which can be difficult to resist.

Figure 6-171 Structure Geometry in Plan of Francisco Oller School

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The structure of this school has a simple elevation. Therefore, it does not have any elevation irregularities. On the other hand, this school has two levels as can be seen in the images from the front of the school (just to the North of it) and from the sides (to the West of the structure). Figure 6-172 shows the front and the floors that the school has with an imagery date from Google Earth 2016. While Figure 6-173 shows the same front, but with a more updated version of the 2020 image. Also, the floors and elevations of the school shown by west side images in Figure 6-174 and Figure 6-175 based on 2016 imagery date.

Figure 6-172 Front of Francisco Oller School (Google Earth - 2016)

Figure 6-173 Front of Francisco Oller School Front (Google Earth - 2020)

Figure 6-174 West Side of Francisco Oller School (April 2016)

Figure 6-175 West Side of Francisco Oller School (April 2016)

6.4.1.3 Adjacency

The position in the urban block of this school is in the middle. This means that Francisco Oller school may have a critical neighboring building that surrounds it. Precisely, this school is located between two existing buildings. One is the Onofre Carballeira middle school on your right (East) and another is the Bahía Urbanización on your left (West) as shown in Figure 6-176.

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Figure 6-329 Evacuation Route Sign (a) through Loiza Street Near to Luis Llorens Torres School (Google Earth – 2016)

Figure 6-330 Evacuation Route Sign (b) through Loiza Street Near to Luis Llorens Torres School (Google Earth – 2016)

Figure 6-331 Evacuation Route Sign (c) through Loiza Street Near to Luis Llorens Torres School (Google Earth – 2016)

Figure 6-332 Evacuation Route Sign (e) through Loiza Street Near to Luis Llorens Torres School (Google Earth – 2016)

Figure 6-333 shows the evacuation route sign (d) located along Las Américas Avenue. This shows on the left the front of the sign that is obstructed by a car according to the Google Earth shot. And on the right, it presents the rear of the same sign without any obstruction.

Figure 6-333 Evacuation Route Sign (d) through Las Américas Avenue Near to Luis Llorens Torres School (Google Earth – 2016)

The evacuation route sign (f) is located on Román Baldorioty de Castro Avenue as shown in Figure 6-334. This is in a direction from East to West along the avenue. This is the only sign that is found and can be seen on the evacuation route of Luis Llorens Torres school through Pellín Rodríguez (Providencia Street) in a North to South direction.

Limitations

- School data was from 2016
  - Population may have varied
  - Some schools may be closed
- Geolocation used for public schools
  - Homeland Infrastructure Foundation-Level Data (HIFLD) was used
    - Further analysis revealed that in some municipalities few schools are misplaced in the dataset
    - The total number of schools identified in tsunami hazard zone may have a small variation

Recommended Further Study (phase II)

- Expand Analysis of Phase I
  - Include private schools in the analysis
    - To have a complete assessment of PR schools
  - Analysis of other municipalities
    - Starting with Loiza, Mayaguez, and Toa Baja
  - Reach more schools with the survey
    - Reevaluate questions

Recommended Further Study (phase II)

- Expand Analysis of Phase I
  - Evaluate alternative heaven places
  - Evaluate walkway conditions after exiting tsunami evacuation zones

Recommended Further Study (phase II)

- Analysis of evacuation timeline and pedestrian flow
  - Propose a complete evacuation timeline
    - i.e., initial gathering time from the classroom to the internal assembly place
    - Evaluate the time of each stage
  - Possible impact of human and environmental factors
  - Possible impact of Walkway conditions
    - i.e., urban furniture and effective width, crossings, etc.

Recommended Further Study (phase II)

- Analysis of evacuation timeline and pedestrian flow
  - Pedestrian and vehicular flow
    - Pedestrian dynamics
      - Impact of the volume of pedestrians
      - Interaction with flow from other large evacuation groups, walking speed of the masses
    - Impact of the traffic condition on roadways
      - Intersections
      - Use of roadway instead of walkway
  - Effect of change in route due to possible obstacles to the path due to structural failures during earthquake
    - i.e., bridges, electric lines, etc.

Recommended Further Study (phase II)

BOX 2: **Tsunami evacuation routes for schools**

Evacuation time for local tsunamis is evaluated and improved in minutes

The evacuation bridge. The tsunami nearly reached the roof of the three-story Okirai Elementary School in Ofunato City, Iwate Prefecture, but all students got away safely over the evacuation bridge. The bridge had been built in October 2011, connecting the school building with a nearby road on higher ground. It shortened the evacuation route from 250 meters to 110 meters, and the evacuation time from 6 minutes to 3 minutes.

The evacuation stairway. The Omoto Elementary School in the town of Iwaizumi, in Iwate Prefecture, is located right in front of a cliff more than 10 meters high. To evacuate to safer ground, children had to take a roundabout route, so an evacuation stairway 30 meters long was built in March 2009. The school building and the gymnasium were inundated by the March 11 tsunami.

Mikio Ishiwatari, Masaru Arakida (2012).

Recommended Further Study (phase II)

- Evaluate required conditions to recommend vertical evacuation

Agenda

1. Introduction - Motivation
2. Stage I – Completed
3. Stage II - Ongoing
4. Further Recommendations
5. References

Stage II Team

- PUPR Students
  - Elisa Marrero-Rodríguez, BSCE, PhD Student
  - Verónica A. Torres Rodríguez, CE Undergraduate Student
- PUPR Faculty
  - Gustavo Pacheco-Crosetti, PhD, PE
  - Miriam Pabón-González, PhD, PE
  - Victor M. Uribe Flórez PhD, MP
- Volpe National Transportation Systems Center
  - Donald Fisher, PhD
  - Alyssa Brodeur, BS
  - Andrew Berthaume, PhD

Objective and Principal Tasks

- Tsunami Evacuation in Schools Stage II
  - Include the Analysis for Private Schools
  - Evacuation Models and Timelines
    - General Emergency Management and Evacuation
    - Tsunami Evacuation
    - Fire Evacuation
    - Hurricane Evacuation
    - Earthquake Evacuation
  - Pedestrian Flow
    - Pedestrian Facilities
    - Factors
    - Mass Pedestrian Flow
    - Pedestrian Dynamics
  - Simulation Software Exploration

General Objective:

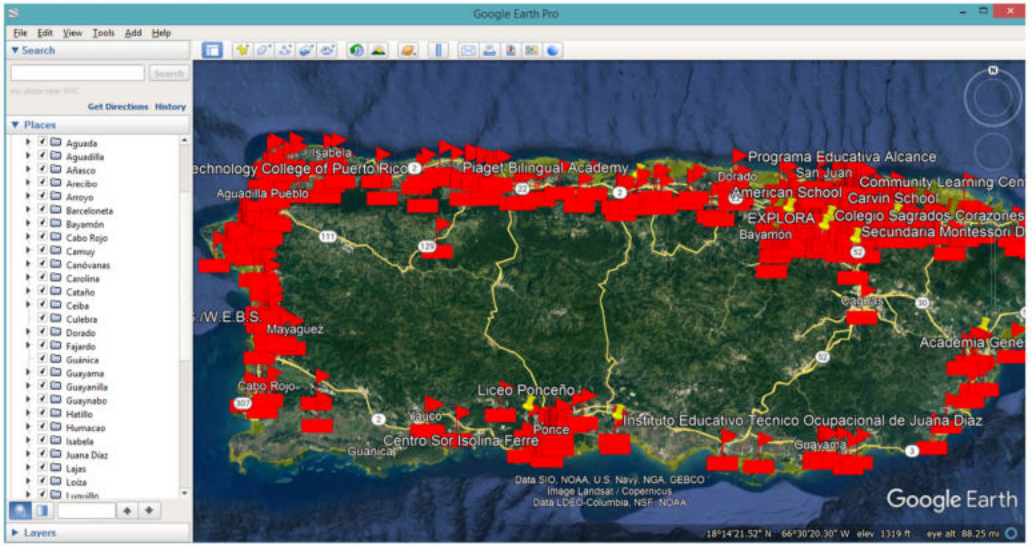
Develop a methodology that allows a better estimate of the evacuation time required for schools (and other facilities)

Contribute to the development of more safe and resilient communities

Private Schools

Google Maps search by municipality/sector

- Geolocate
- Create a GIS layer

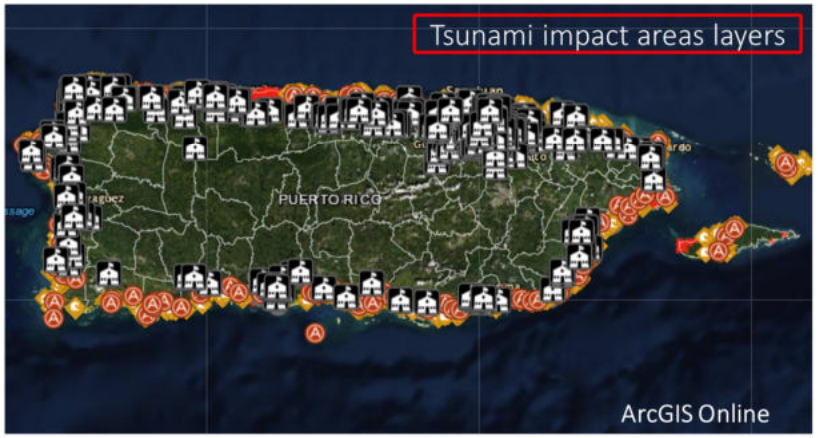


Private Schools

Insert Layers in ArcGIS

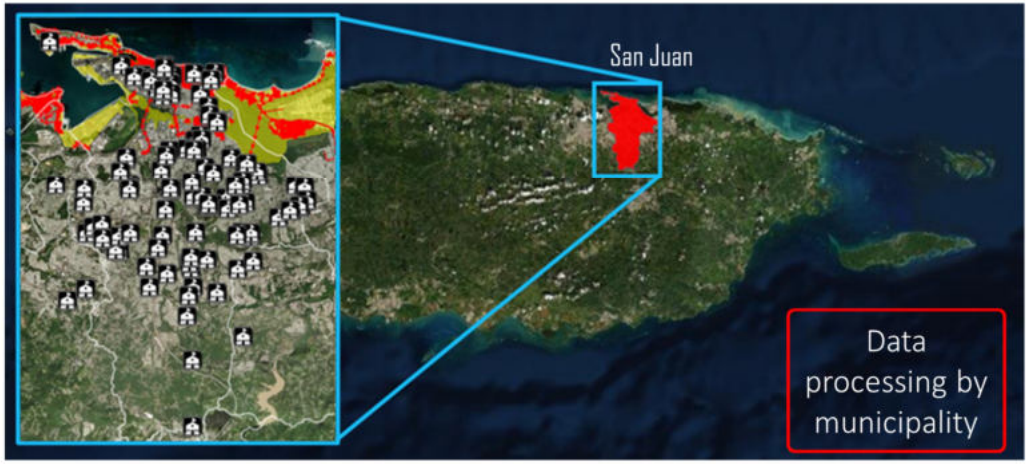
Legend

- Private Schools
- Evacuation Zones
- Flood Zones
- Evacuation Routes
- Evacuation Routes Signs
- Assembly Points
- Sirens



Private Schools

Assess schools in tsunami hazard zones (evacuation zones)



Private Schools

Municipality	Schools in Tsunami Hazard Zone	Voting Center	Shelter	Population
Aguada	2	0	0	22
Aguadilla	1	0	0	150
Añasco	0	0	0	0
Arecibo	3	0	0	110
Arroyo	0	0	0	0
Barceloneta	0	0	0	0
Bayamón	0	0	0	0
Cabo Rojo	0	0	0	0
Camuy	0	0	0	0
Canóvanas	0	0	0	0
Carolina	3	0	0	646
Cataño	1	0	0	0
Ceiba	0	0	0	0
Culebra	0	0	0	0
Dorado	1	1	0	668
Fajardo	0	0	0	0
Guánica	0	0	0	0
Guayama	0	0	0	0

Private Schools

Municipality	Schools in Tsunami Hazard Zone	Voting Center	Shelter	Population
Guayanilla	0	0	0	0
Guaynabo	0	0	0	0
Hatillo	0	0	0	0
Humacao	0	0	0	0
Isabela	0	0	0	0
Juana Díaz	0	0	0	0
Lajas	0	0	0	0
Loíza	2	1	0	394
Luquillo	0	0	0	0
Manatí	0	0	0	0
Maunabo	0	0	0	0
Mayagüez	0	0	0	0
Naguabo	0	0	0	0
Patillas	0	0	0	0
Peñuelas	0	0	0	0
Ponce	2	0	0	108
Quebradillas	0	0	0	0
Rincón	1	0	0	166
Río Grande	0	0	0	0

Private Schools

Municipality	Schools in Tsunami Hazard Zone	Voting Center	Shelter	Population
Salinas	0	0	0	0
San Juan	7	1	0	2350
Santa Isabel	1	0	0	Unknown
Toa Baja	11	1	0	1987
Vega Alta	0	0	0	0
Vega Baja	0	0	0	0
Vieques	0	0	0	0
Yabucoa	0	0	0	0
Yauco	0	0	0	0
Total	**35**	**4**	**0**	**6,601**

Municipalities with no schools in tsunami hazard zone
Municipalities with 1 to 3 schools in a tsunami hazard zone
Municipalities with 4 to more schools in a tsunami hazard zone
Total results

12/46 coastal municipalities with schools in tsunami hazard zones

Data from "Compendio Estadístico sobre la educación básica privada de Puerto Rico, año 2020-2021, Instituto de Estadísticas de PR"

Public + Private Schools

	Schools	Voting Centers	Shelters	Population
Total Public Schools	**74**	**34**	**9**	**20,895**
Total Private Schools	**35**	**4**	**0**	**6,601**
Total Public + Private Schools	**109**	**38**	**9**	**27,496**

Public + Private Schools

Municipality	Schools in Tsunami Hazard Zone	Voting Center	Shelter	Population	Cambio
Aguada	5	1	0	1,479	Stage 2
Aguadilla	4	1	0	669	
Arecibo	4	0	0	207	
Carolina	5	0	0	646	
Cataño	5	2	0	1,465	Stage 1
Loíza	10	5	3	2,795	
Mayagüez	9	5	1	3,247	
Ponce	6	2	0	1,685	
Salinas	4	3	0	541	
San Juan	16	6	0	4,433	
Toa Baja	19	5	2	4,789	
Total	**87**	**30**	**6**	**21,956**	
	80%	79%	67%	80%	

11 critical municipalities, about 80% of all indicators

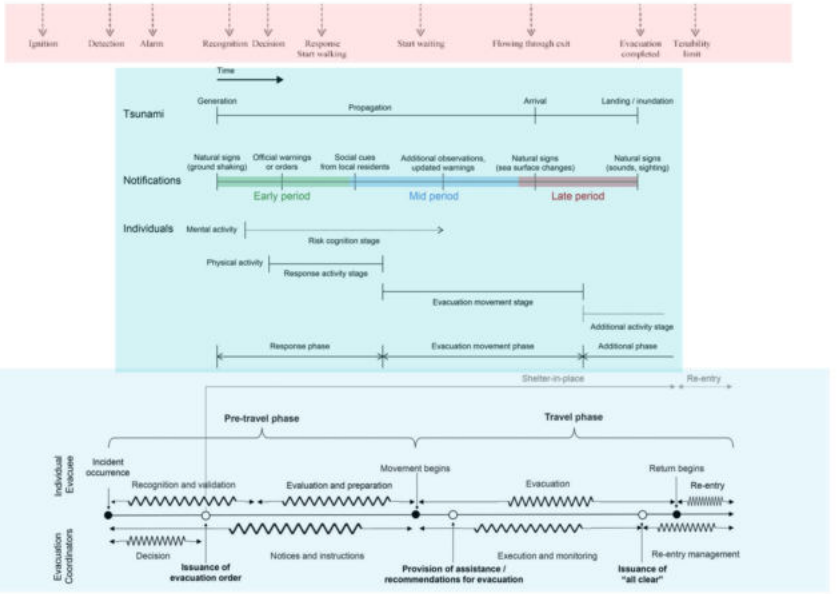
Evacuation Timelines

TIMELINES COMPARISON

Ng & Chow 2006

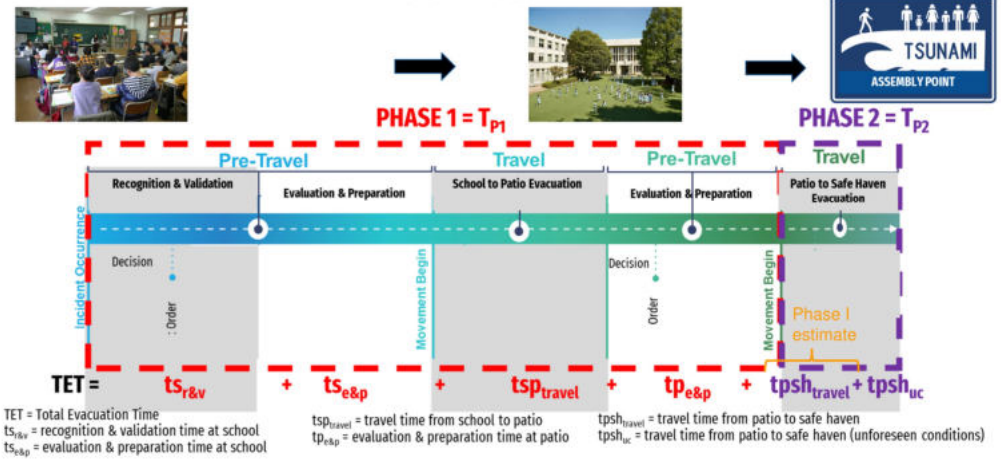
Makinoshima 2020

Wang et al. 2021



Evacuation Timelines

Timeline, TET = T_{P1} + T_{P2}



TET = Total Evacuation Time
$ts_{r\&v}$ = recognition & validation time at school
$ts_{e\&p}$ = evaluation & preparation time at school

tsp_{travel} = travel time from school to patio
$tp_{e\&p}$ = evaluation & preparation time at patio

$tpsh_{travel}$ = travel time from patio to safe haven
$tpsh_{uc}$ = travel time from patio to safe haven (unforeseen conditions)

Elisa Marrero Dissertation Proposed Model

Simulation Software

Table 1. Overall features of egress models

Model	Available to public	Modeling Method	Purpose	Grid/ Structure	Perspective of M/O	Behavior	Movement	Fire data	CAD	Visual	Valid
FPETool	Y	M	1	N/A	G	N	UC	N	N	N	N
EVACNET4	Y	M-O	1	C	G	N	UC	N	N	N	FD
TIMTEX	Y	M	4	C	G/I	N	D	N	N	N	PE
WAYOUT	Y	M	5	C	G	N	D	N	N	2-D	FD
STEPS	Y	M/PB	1	F	I	N/I	P,E	N	Y	3-D	C
PedGo	Y	M/PB	1	F	I	I	P,E (CA)	N	Y	2-D	FD
PED/PAX	Y/N?	PB	3	C	G	I	D	N	Y	2,3-D	N
Simulex	Y	PB	1	Co.	I	I	ID	N	Y	2-D	FD,PE
GridFlow	Y	PB	1	Co.	I	I	D	N	Y	2,3-D	FD, PE
ASERI	Y	B-RA	1	Co.	I	R/C, P	ID	Y1,2	N, F	2,3-D	FD
BldEXO	Y	B	1	F	I	R/C, P	P, E	Y1,2	Y	2,3-D	FD
EXITT	Y	B	2	C	I	R/C	C	Y1,2	N	2-D	N
Legion	Y	B	1	Co.	I	AI	D,C	Y?	Y	2,3-D	FD,OM
PathFinder	N1	M	1	F	I/G	N	D	N	Y	2-D	N
EESCAPE	N1	M	5	C	G	N	D	N	N	N	FD
Myriad	N1	M	1	N/A	I	N	D	N	Y	2-D	3P
ALLSAFE	N1	PB	5	C	G	I	Un.F	Y1,2	N	2-D	OM
CRISP	N1	B-RA	1	F	I	R/C, P	E,D	Y3	Y	2,3-D	FD
EGRESS 2002	N1	B	1	F	I	R/C, P	P,D (CA)	Y2	N	2-D	FD
SGEM	N2	M/PB	1	F	I	N/I	E,D (CA)	N	Y	2-D	FD, OM
Egress Complexity	N2	M/PB	5	C	G/I	N	Ac K, FA	N	N	N	OM
EXIT89	N2	PB	1	C	I	I/G(smk)	D	Y1	N	N	FD
BGRAF	N2	B	1	F	I	R/C, P	UC?	Y1,2	N, F	2-D*	FD
EvacSim	N2	B	1	F	I	R/C, P	D	Y2	N	N	N
Takahashi's Fluid	N3	M-O	1	C	G	N	FA-D	N	N	2-D	FD
EgressPro	N3	M	5	C	G	N	D	Y2	N	N	N
BFIRES- 2	N3/U	B-RA	4	F	I	R/C, P	UC	Y2	N	N	N
VEgAS	N3/U	B	1	F	I	AI	ID	Y1?	Y	3-D	N
Magnetic Model	U	M	1	F	I	I	FA	N	N	2-D	N
E-SCAPE	U	B	1	C	I	R/C, P	O/E	Y2	N	2-D	N

* indicates that a category is unclear or unknown

Technical Note 1471

A Review of Building Evacuation Models

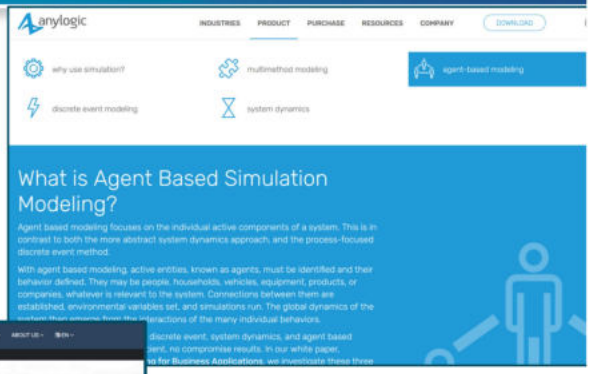
July 2005

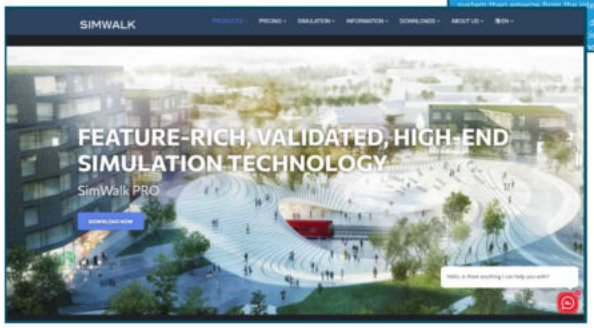
Erica D. Kuligowski
Richard D. Peacock

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Simulation Software

Anylogic

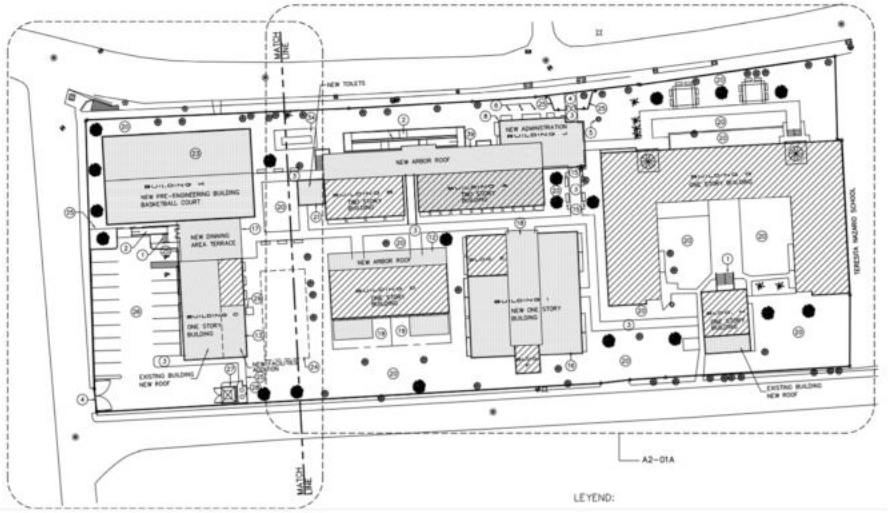




Simwalk

Simulation Software

JOSE RODRIGUEZ DE SOTO SCHOOL - GUANICA, PR
ELEMENTARY SCHOOL FLOOR PLAN



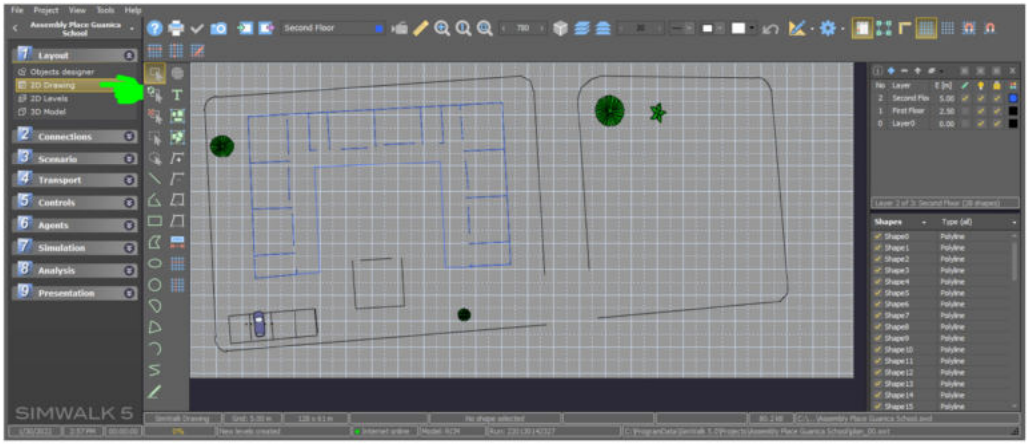
Simulation Software

SimWalk Pro

Only as demonstration

1

Layout

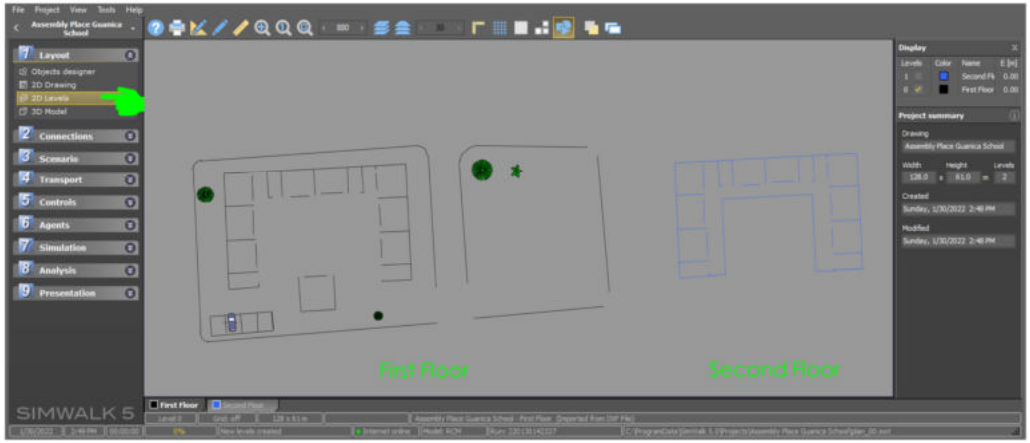


Simulation Software

SimWalk Pro

1

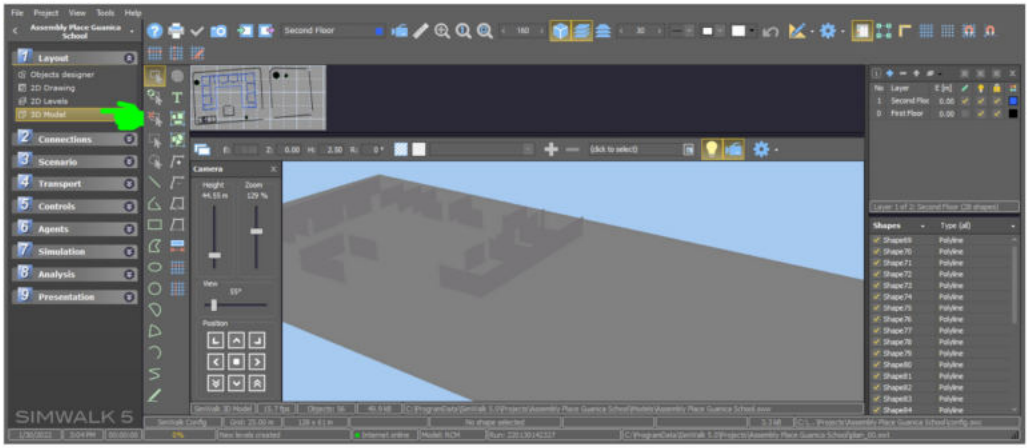
Layout



Simulation Software

SimWalk Pro

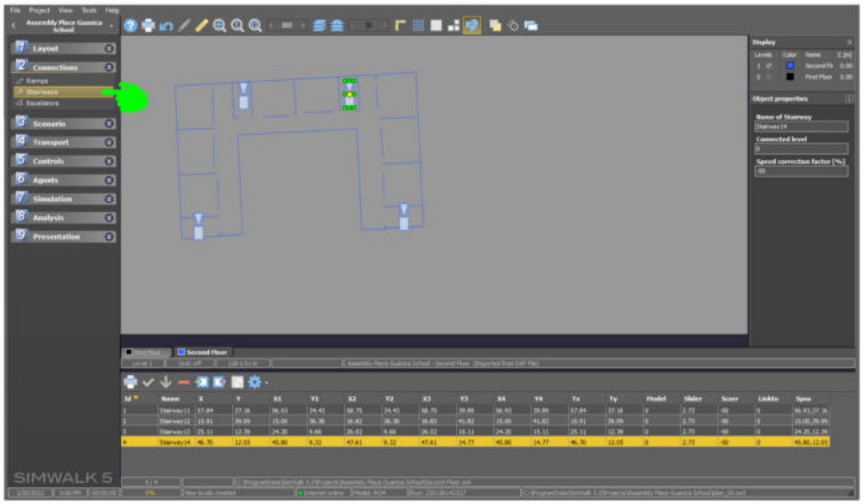
1
Layout



Simulation Software

SimWalk Pro

2
Connections

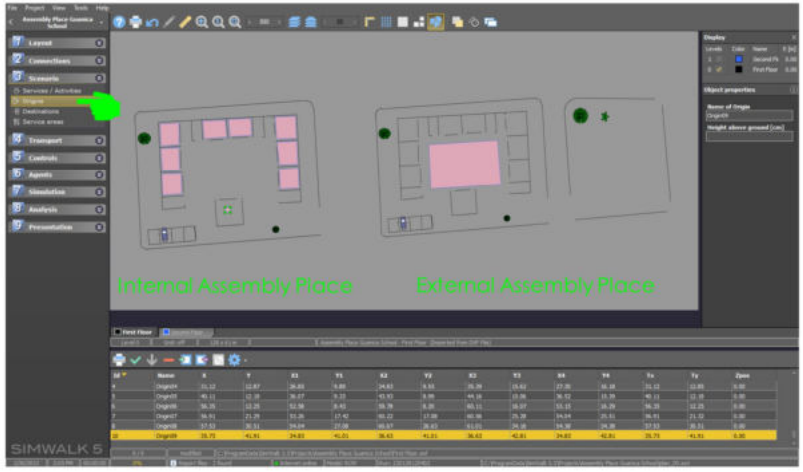


Simulation Software

SimWalk Pro Origins

3
Scenario

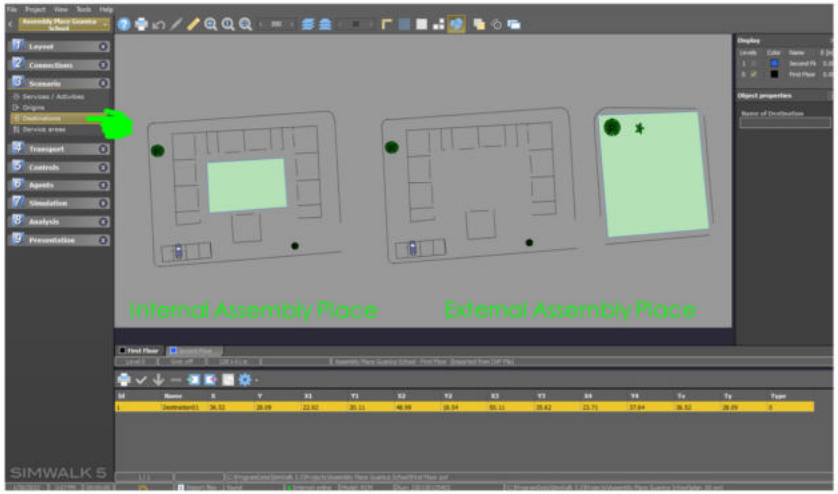
- 8 classroom per floor



Simulation Software

SimWalk Pro Destinations

3
Scenario



Simulation Software

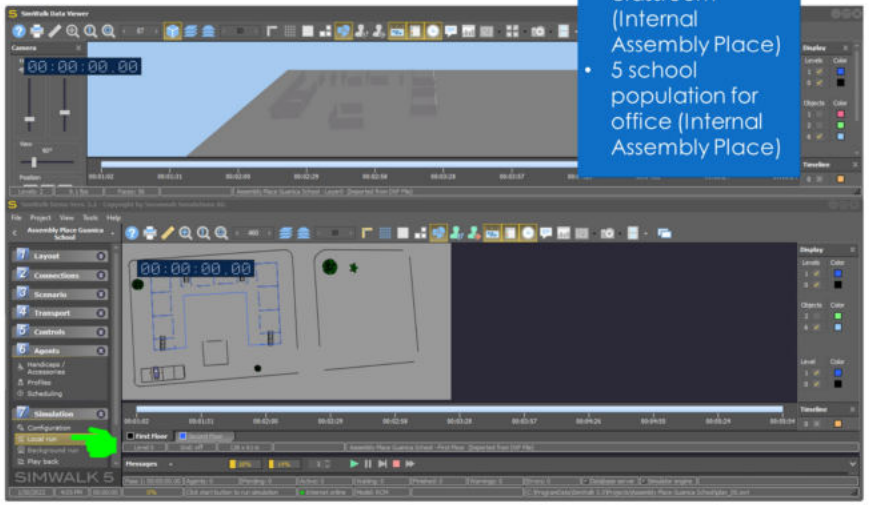
SimWalk Pro

7

Simulation

Agents

- 25 school population per classroom (Internal Assembly Place)
- 5 school population for office (Internal Assembly Place)

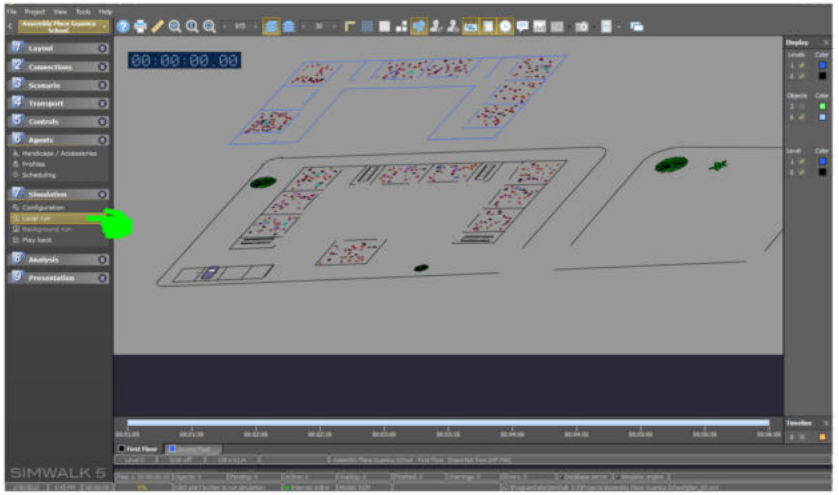


Simulation Software

SimWalk Pro

7

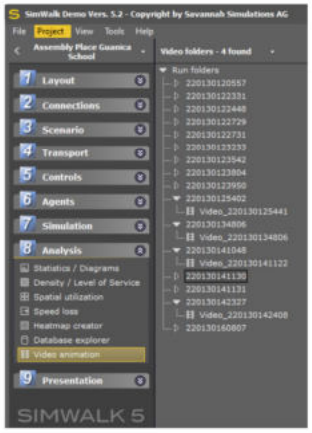
Simulation

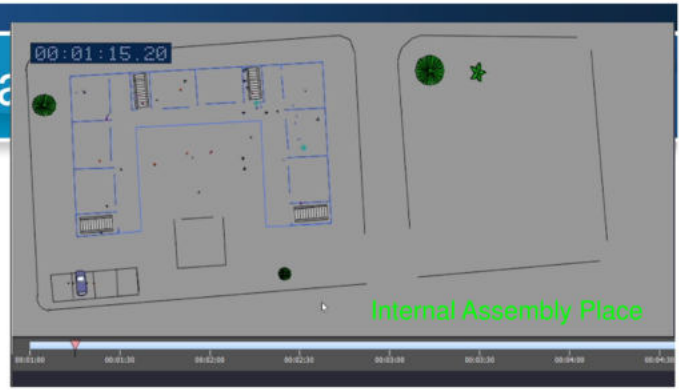


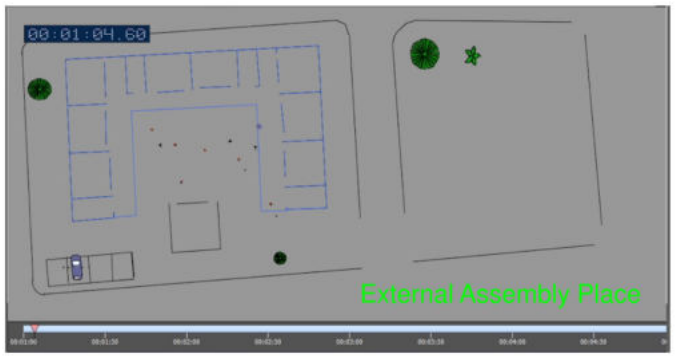
Simula

8

Analysis





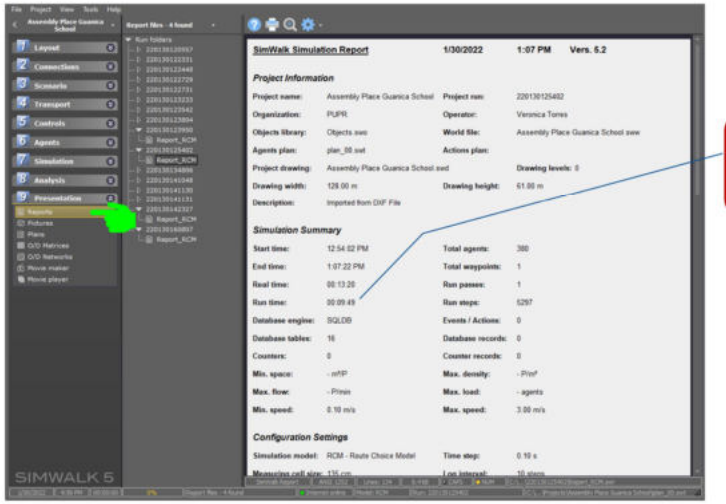


Simulation Software

SimWalk Pro

9

Results



Internal Assembly Place
00:09:48.70

External Assembly Place
00:04:41.00

00 : 14 : 29 . 70

Just for demonstration
Needs:
Calibration
Validation

Evacuation Timelines

Timeline, TET = T_{P1} + T_{P2}

PHASE 1 = T_{P1}

PHASE 2 = T_{P2}

10 m | 2 m | 17 m

29 m

Possible scenario (only as a demonstration) …

Preliminary Conclusions

- The evacuation process time estimates should include
  - All the stages (timeline)
  - Specific factors and conditions
  - We expect to contribute to this matter
    - Results of this research and development stage
    - Emergency Evacuation Research Center

Current Activities

- School data gathering
  - School drawings
- School contact
  - Previous drills information
  - Coordinate participation in future drills

Any contact is appreciated

- Pedestrian dynamics study and comparisons
  - Factors, evacuation speeds, simulation models
- Simulation Software
  - Training
  - Evaluation
  - Selection
  - Calibration
  - Validation

Summer internship

Complementary Findings

- Public Schools in the THZ Included in the Current Infrastructure Plan
  - San Juan — Luis Rodriguez Castro
  - San Juan — Julian E. Blanco
  - Ponce — Dr. Alfredo M. Aguallo
  - Cataño — Onofre Carballeira

Only 4 of the 74 in the tsunami hazard (evacuation) zone Appropriate?

Agenda

1. Introduction - Motivation
2. Stage I – Completed
3. Stage II - Ongoing
4. Further Recommendations
5. References

Preliminary Recommendations

https://fronterasblog.com/

Preliminary Recommendations

- A Comprehensive (Holistic) Approach to Schools Rehabilitation is Highly Recommended
  - Focus on safety and resilience of the community
  - Not limited to evaluate one hazard condition, multihazard approach
    - Earthquake
    - Tsunamis
    - Winds
    - Flooding
    - Landslides
    - Liquefaction
  - Not limited to evaluate one vulnerability condition

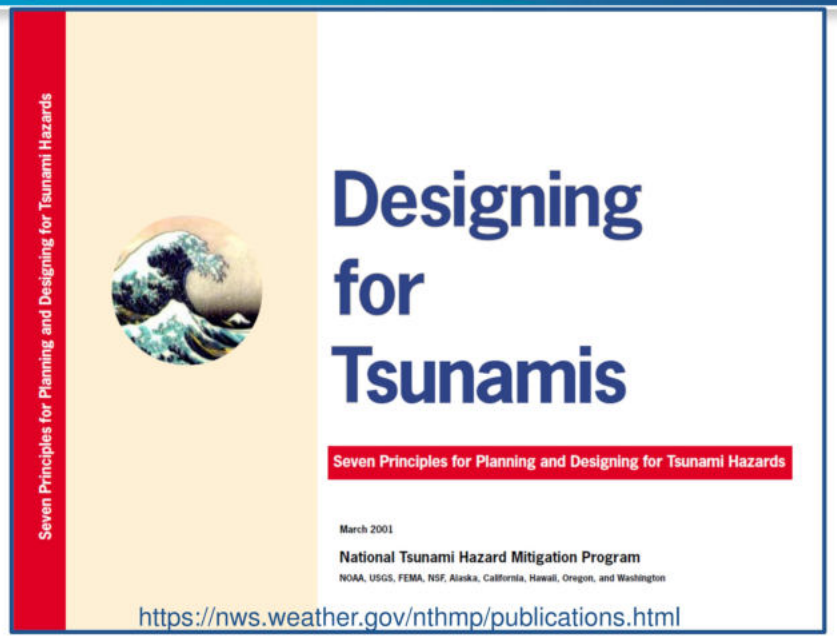
Preliminary Recommendations

- In Seismic Rehabilitation Consider
  - Complete structural condition assessment
    - Design standards used when built
    - As built conditions and modifications
    - Steel detailing and material properties
    - Damages and deterioration
    - Irregularities in plan and elevation
    - Current seismic capacity/response estimate
    - Target seismic response …

Preliminary Recommendations

- In Seismic Rehabilitation Consider
  - Nonstructural elements
    - Responsible for most of the injuries and fatalities in well design buildings
  - Location and evacuation requirements
    - Landslides?
    - Liquefaction?
    - Tsunami hazard zone?
      - Is vertical evacuation required?
      - Are special design requirements?
        - » hydrostatic, hydrodynamic, buoyancy, water borne debris, scouring

Preliminary Recommendations



https://nws.weather.gov/nthmp/publications.html

Guidelines for Design of Structures for Vertical Evacuation from Tsunamis

Third Edition

FEMA P-646 / August 2019 (2008, 2012, 2019)

FEMA

Figure A-2 Life-Saving Tower

Figure 3-5 Tsunami evacuation refuge over a cafeteria and gymnasium at Ocosta Elementary School, Westport, Washington (photo courtesy of P. Akerlund)

School in Washington State, FEMA P-646

Figure A-1 Location of Ocosta Elementary and Junior-Senior High Schools, Westport, Washington.

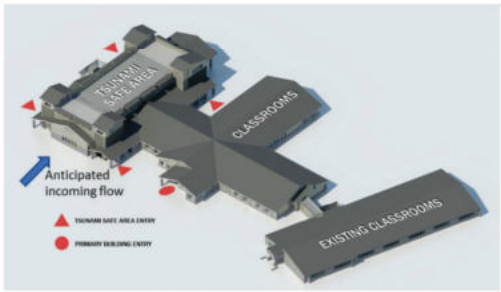


Figure A-2 Tsunami refuge area on roof of new activities wing Ocosta Elementary School (image courtesy ASCE ar TCF Architecture).

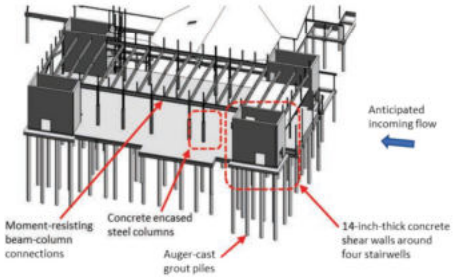


Figure A-3 Structural system details for the new activities wing and tsunami refuge structure (image courtesy ASCE and TCF Architecture).

Preliminary Recommendations

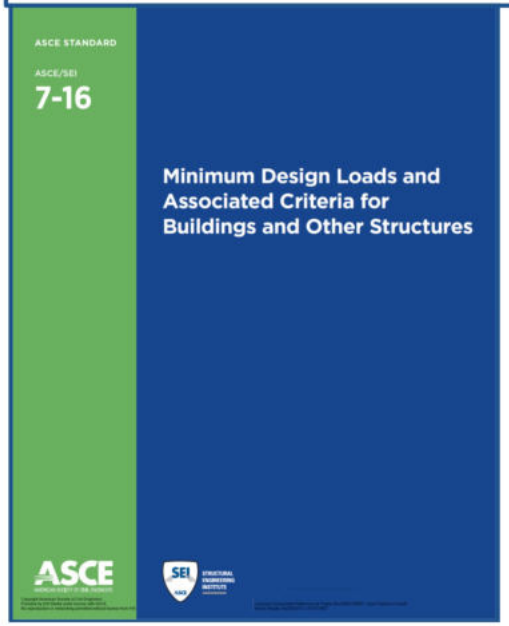
Apparently not enough time to evacuate to nearby higher ground

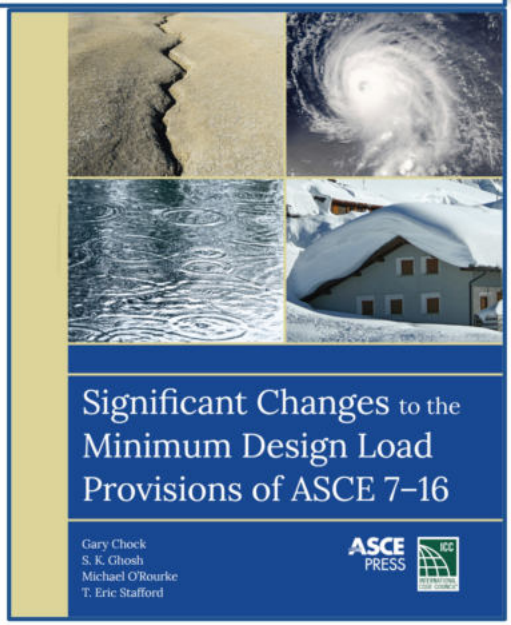
Figure A-4 Refuge at Shirahama Beach Resort (photo courtesy of N. Shuto).

Vertical evacuation refuge examples, FEMA P-646

Tsunami Loads and Effects — Addition

Chapter 6





Preliminary Recommendations

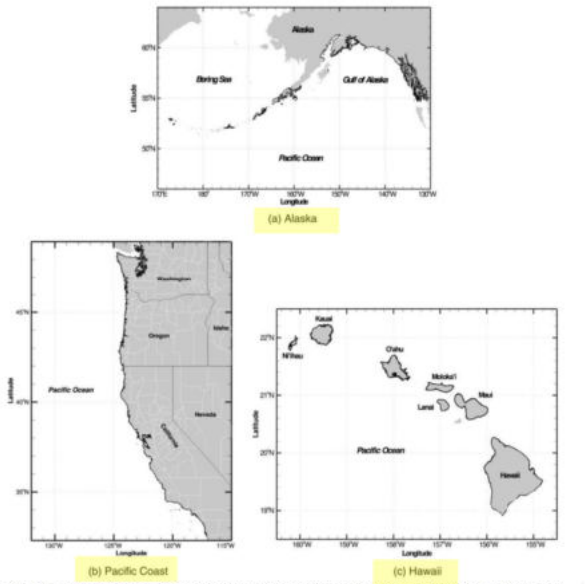


FIGURE 6.1-1 Extent of ASCE Tsunami Design Geodatabase[1] of Geocoded Reference Points of Runup and Associated Inundation Limits of the Tsunami Design Zone[2]

Runup and associated Inundation Limits of the Tsunami Design Zone

Not available for PR in ASCE7-16

Procedure:

- very well established in FEMA 646 2008 & 2012
- Incorporated as a referenced Code Standard in ASCE 7 2016
- Should PR determine the required parameters based on PRSN studies?

Preliminary Recommendations

- Comprehensive (Holistic) Approach to Rehabilitation – not limited to the building
  - Evacuation routes
    - Do the they require improvements?
    - What are the conflicts between vehicular and pedestrian scape routes?
  - People preparedness
    - Is people trained in
      - Following a scape route?
      - Assessing dangerous conditions on the route?
      - Selecting alternative scape routes?

Practice evacuation

www.weather.gov/tsunamisafety, Tsunami Preparedness, Building a Weather-Ready Nation

Focus on safety and resilience of the community

Preliminary Recommendations

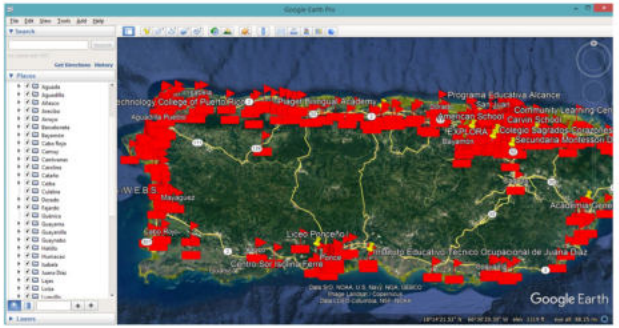
(https://blog.derrama.org.pe/origen-de-la-frase-a-ojo-de-buen-cubero/l)

Universidad Isabel I | DEL DICHO AL HECHO HISTÓRICO

(https://www.ui1.es/blog-ui1/del-dicho-al-hecho-historico-de-donde-viene-la-expresion-ojo-de-buen-cubero)

Preliminary Recommendations

- Comprehensive (Holistic) Approach to Rehabilitation
  - Reliable Data for Analysis and Planning
    - GIS based, broad and inclusive, centralized, accessible, and validated information is essential
      - Support data-based decision processes
      - Allow what-if analysis
      - Fosters research on community safety and resilience



Preliminary Recommendations

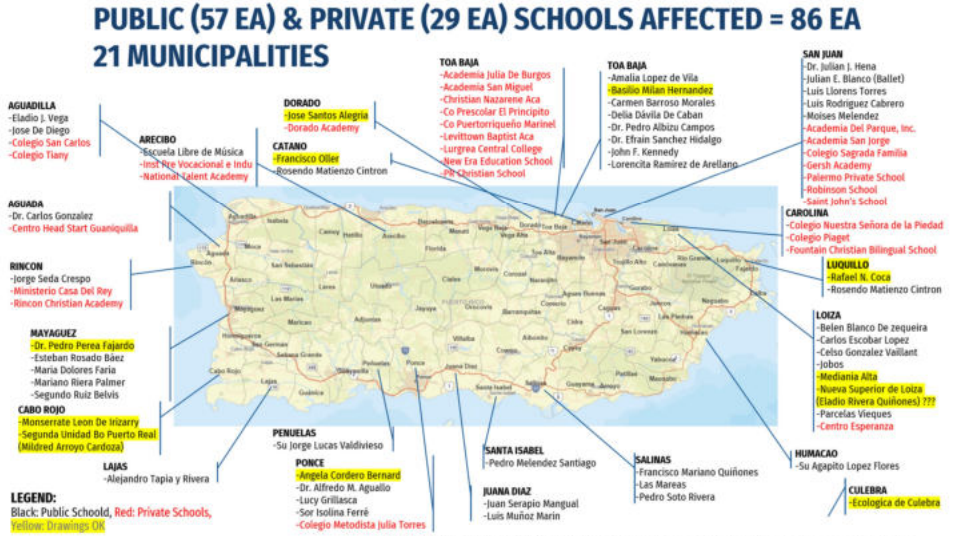
- Most significant barrier/problem encountered
  - School data
    - Availability
    - Accessibility
    - Reliability
    - Completeness
    - Not updated
    - Disperse

Información geolocalizada

Preliminary Recommendations

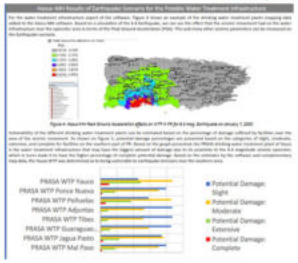
- Example of data search difficulty

8 weeks work
11 of 86 targeted



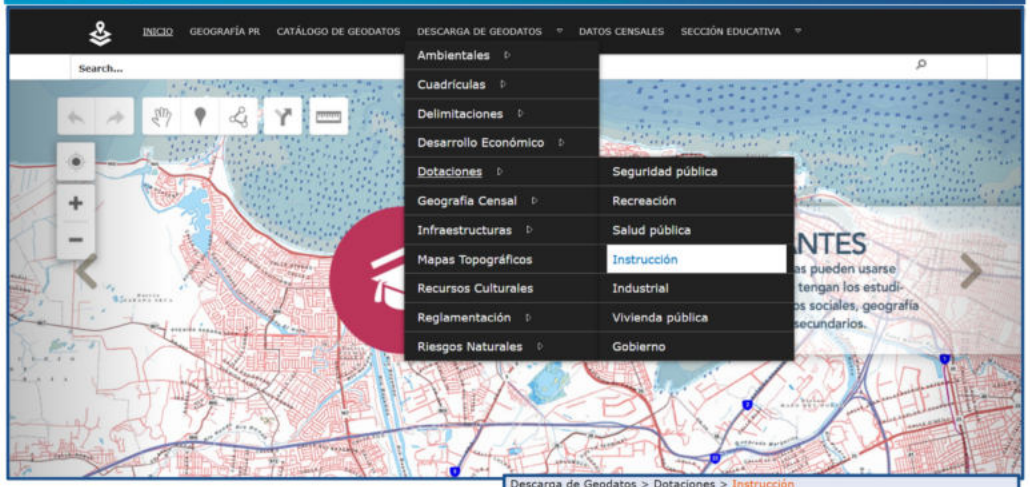
Preliminary Recommendations

- Other Example of lack of integrated data/tools
  - Risk & Vulnerability Assessment on Water Treatment Infrastructure against Natural Hazards in Puerto Rico
    - Abdiel Lugo Montes, EnvE Student
    - Explore Hazus to use multiple hazard analysis as a planning tool
      - The hurricane model was not available for PR
      - The flooding model was incompatible with the Hazus version for Earthquake and Tsunami, making the multiple hazard scenario analysis complicated and very time consuming.



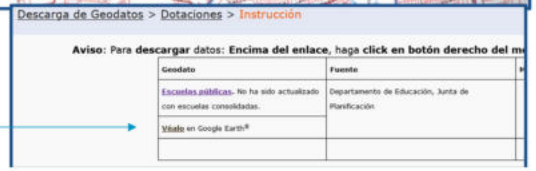
http://prcrepository.org:8080/xmlui/handle/20.500.12475/944

Preliminary Recommendations



https://gis.pr.gov/Pages/default.aspx

Google Earth File
public_schools.kmz



Preliminary Recommendations

- CIAPR should foster
  - The development of reliable, accessible, comprehensive, updated, geolocated data
  - The information/data driven decision-making process

Información geolocalizada

Thanks

- Students
- PUPR support
- VOLPE collaboration

- Special thanks to the Puerto Rico Seismic Network
  - Excellent work
  - Reliable, accessible, geolocated data
  - Cooperative attitude

- Audience

Contact Information

- Gustavo Pacheco-Crosetti, PhD, PE
  - gpacheco@pupr.edu
- Miriam Pabón-González, PhD, PE
  - MPabon@pupr.edu
- Elisa Marrero Rodríguez
  - marrero_31038@students.pupr.edu
- Verónica A. Torres Rodríguez
  - torres_110592@students.pupr.edu

Agenda

1. Introduction - Motivation
2. Stage I – Completed
3. Stage II - Ongoing
4. Further Recommendations
5. References

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