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Seismic hazard for the Dutch Caribbean

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Content

1 Introduction

The Dutch Caribbean[1] are located in a region where earthquakes are common. This is due to the tectonic activity in this area (Figure 1-1). Subduction of the North and South American plates under the Caribbean plate causes volcanism and earthquakes.

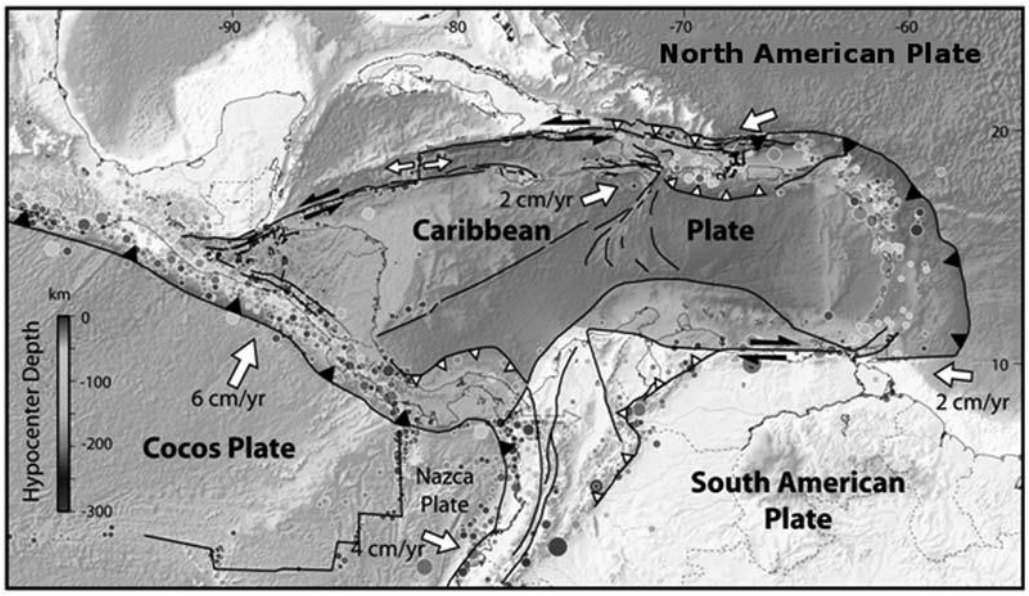

Figure 1-1 Tectonic setting of the Caribbean, the subduction of the North and South American plates under the Caribbean plate is indicated with arrows. The line with black triangles depicts the subduction zone. Circles show large earthquakes in the region (1974-2010). Source: Bozzoni et al (2011).

The seismic hazard is one of the natural hazards present in the Caribbean. Other natural hazards in this region include hurricanes, tsunamis, volcanic eruptions, droughts and flooding. The European PARATUS project (https://www.paratus-project.eu/) aims to collaborate with stakeholders to increase preparedness of first and second responders in the face of multi-hazard events and to reduce the risks related to impacts on various sectors that result from complex disasters.

During building projects, the expected ground acceleration caused by earthquakes should be taken into account. This is called the seismic hazard. In seismic hazard analysis, both PGA (Peak Ground Acceleration) and SA (Spectral Acceleration) are used to describe the intensity of ground shaking, but they measure different aspects of seismic motion. PGA is a measure of the peak shaking intensity, while SA provides the acceleration at a specific frequency. For example, SA(0.2 s) indicates the Spectral Acceleration with a period of 0.2 seconds. Structures are sensitive to vibrations with specific frequencies, depending on the structure layout and height. The unit for PGA and SA is the gravitational acceleration *g* where *g* equals 9.81 m/s^2.
Other terminology used is the "probability of exceedance" and the "return period". A 10% probability of exceedance in 50 years, means that there is a 10% chance that the seismic ground motion will exceed the specified level in a period of 50 years. A

1 These consist of the special municipalities of Bonaire, Sint Eustatius and Saba (Caribbean Netherlands) and the countries Aruba, Curaçao and Sint Maarten.

return period (RP) refers to the estimated average amount of time between events that exceed a certain level of ground shaking. When the return period is 475 years, an event is expected to occur once every 475 years on average. Commonly used return periods are 475 and 2475 years. The return period to be used depends on the type and use of the building. The seismic hazard is often calculated for so called "rock" conditions. If soil conditions deviate from rock conditions, a correction has to be applied.

The legal framework for building regulations differs from island to island. It is your responsibility to consult applicable laws and regulations in your region when you have construction plans.

For the eastern Caribbean a seismic hazard map can be downloaded from the University of the West Indies Seismic Research Centre (UWI-SRC) website which is based on research by Bozzoni et al. (2011). Recently, a new study was published (Zimmerman et al., 2022) containing detailed seismic hazard information for a wider Caribbean region. In addition, a global map of seismic hazard is available (Johnson et al., 2023). This report summarizes results from these three studies for the Dutch Caribbean.

2 The eastern Caribbean – Source: UWI-SRC

The UWI-SRC created seismic hazard maps following Bozzoni et al. (2011) for the eastern Caribbean. These maps can be found on-line https://uwiseismic.com/downloads/seismic-hazard-map/. Bozzoni et al. (2011) first completed the earthquake catalogue for the region up to 2009 and then used Ground Motion Prediction Equations (GMPEs) available at the time to calculate the seismic hazard. The seismic hazard was calculated for rock conditions, for return periods of 95, 475, 975 and 2475 years, for PGA and for SA with a period of 0.2 and 1.0 seconds. An example of a seismic hazard map depicting the mean values of PGA for a return period of 475 years is shown in Figure 2-1.

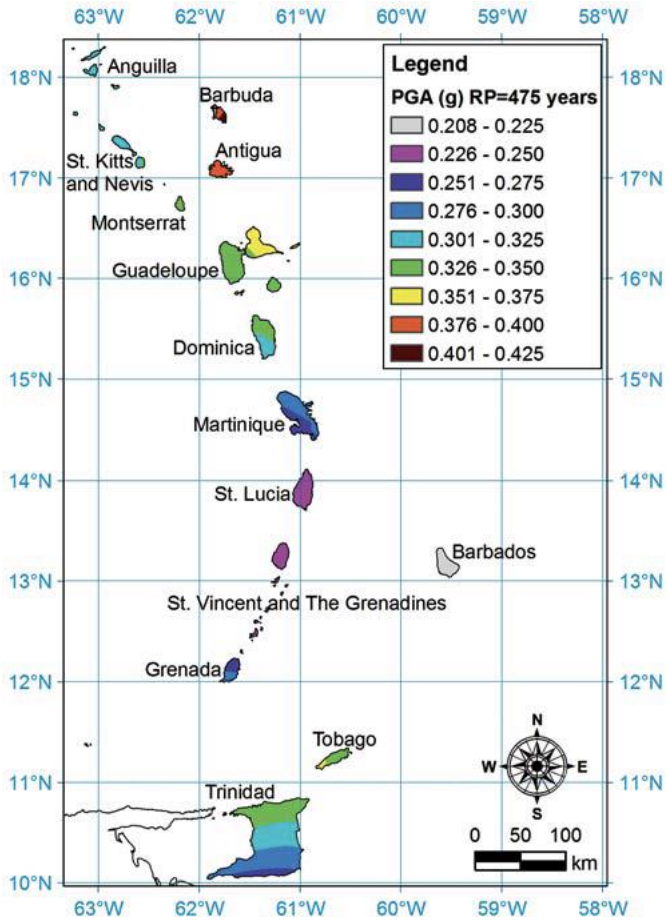

Figure 2-1 Seismic hazard map for the eastern Caribbean showing the mean values of PGA for a return period of 475 years. Source: Bozzoni et al. (2011).

Sint Maarten, Saba and Sint Eustatius are not indicated by name on this map, but their coordinates and complementary PGA and SA values are listed in Table 2-1. For each of the twelve available maps the color coded PGA ranges for the different islands were read and listed in Table 2-1. Because each color represents a range and not a specific value, ranges are reported in Table 2-1.

Table 2-1 Seismic hazard values (in g) of PGA and SA for different return periods for Sint Maarten, Saba and Sint Eustatius. Source: https://uwiseismic.com/downloads/seismic-hazard-map/.

	Island	Sint Maarten	Saba	Sint Eustatius
	Capital	Philipsburg	The Bottom	Oranjestad
	Latitude capital	18.029	17.626	17.482
	Longitude capital	-63.045	-63.249	-62.983
Hazard parameter	Return period (years)			
Peak Ground Acceleration, PGA	95	0.15-0.20	0.15-0.20	0.15-0.20
	475	0.30-0.35	0.25-0.30	0.25-0.30
	975	0.35-0.40	0.35-0.40	0.35-0.40
	2475	0.50-0.60	0.50-0.55	0.50-0.55
Spectral Acceleration, SA (0.2 s)	95	0.3-0.4	0.3-0.4	0.3-0.4
	475	0.7-0.8	0.7-0.8	0.7-0.8
	975	1.0-1.2	0.8-1.0	0.8-1.0
	2475	1.4-1.5	1.3-1.4	1.4-1.5
Spectral Acceleration, SA (1.0 s)	95	0.05-0.10	0.05-0.10	0.05-0.10
	475	0.20-0.25	0.20-0.25	0.20-0.25
	975	0.25-0.30	0.25-0.30	0.25-0.30
	2475	0.40-0.45	0.40-0.45	0.40-0.45

The seismic hazard values for Sint Maarten, Saba and Sint Eustatius mostly fall in the same range when looking at a specific return period and hazard parameter. In a few cases there are small deviations from this trend. This is caused by the proximity of each island to the subduction zone and hence the slight differences in earthquake activity. Seismic hazard always increases for a longer return period. This is to be expected, because larger magnitude earthquakes (higher amplitudes of the shaking) occur less frequent (longer return period).

3 The whole Caribbean region – source: Zimmerman et al.

Recently Zimmerman et al. (2022) recalculated the seismic hazard for the Caribbean. They did this for the whole Caribbean region using more recent GMPE's than Bozzoni et al. (2011). They also made slightly different assumptions in the calculations. Zimmerman et al. (2022) calculated the seismic hazard of PGA for return periods of 475 and 2475 years. The seismic hazard maps are shown in Figure 3-1 and Figure 3-2.

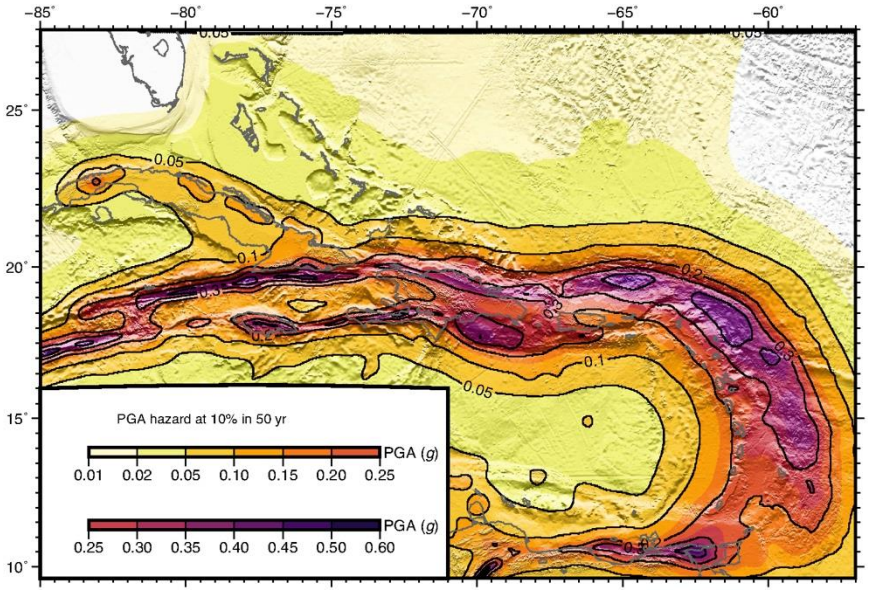

Figure 3-1 Seismic hazard map of PGA (in g) for rock conditions and a probability of exceedance of 10% in 50 years, corresponding to a return period of 475 years. Source: Zimmerman et al. (2022).

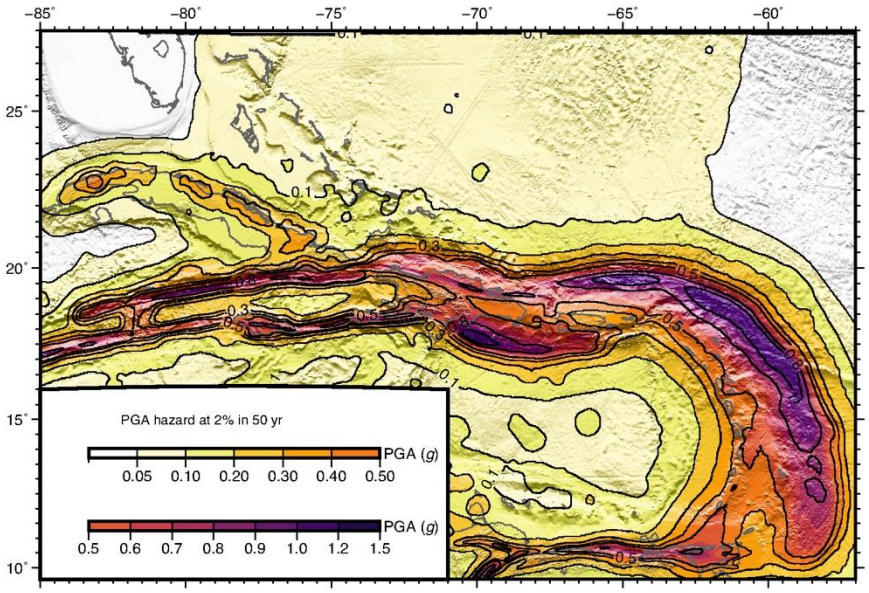

Figure 3-2 Seismic hazard map of PGA (in g) for rock conditions and a probability of exceedance of 2% in 50 years, corresponding to a return period of 2475 years. Source: Zimmerman et al. (2022).

Generally speaking the seismic hazard for the islands of Sint Maarten, Saba and Sint Eustatius is higher than for the islands of Aruba, Curaçao and Bonaire. This is due to the location of each island with respect to the subduction zone.

Individual seismic hazard values are difficult to pinpoint from Figure 3-1 and Figure 3-2. Zimmerman therefore provided the PGA values for the six islands of the Dutch Caribbean directly from the dataset (personal communication). The PGA values for return periods of 475 and 2475 years for the capital cities and the minimum and maximum per island are included in Table 3-1 for Sint Maarten, Saba and Sint Eustatius, and in Table 3-2 for Aruba, Curaçao and Bonaire.

Table 3-1 Seismic hazard values of PGA (in g) for different return periods for Sint Maarten, Saba and Sint Eustatius. For each island the value for the capital and the range for the whole island are indicated. Source: Zimmerman et al. (2022).

	Island	Sint Maarten	Saba	Sint Eustatius
	Capital	Philipsburg	The Bottom	Oranjestad
Return Period (years)	Latitude capital	18.029	17.626	17.482
	Longitude capital	-63.045	-63.249	-62.983
475	Capital	0.245	0.185	0.195
	Minimum	0.225	0.185	0.195
	Maximum	0.255	0.195	0.205
2475	Capital	0.505	0.395	0.425
	Minimum	0.485	0.395	0.415
	Maximum	0.535	0.405	0.435

Table 3-2 Seismic hazard values of PGA (in g) for different return periods for Aruba, Curaçao and Bonaire. For each island the value for the capital and the range for the whole island are indicated. Source: Zimmerman et al. (2022).

	Island	Aruba	Curaçao	Bonaire
	Capital	Oranjestad	Willemstad	Kralendijk
Return Period (years)	Latitude capital	12.521	12.109	12.152
	Longitude capital	-70.031	-68.936	-68.274
475	Capital	0.095	0.055	0.045
	Minimum	0.075	0.035	0.045
	Maximum	0.115	0.065	0.055
2475	Capital	0.185	0.115	0.105
	Minimum	0.145	0.085	0.095
	Maximum	0.235	0.135	0.115

4 The whole Caribbean region – source: GEM

Zimmerman et al. (2022) also refers to the Global Earthquake Model (GEM) that was implementing an update around the same time (Johnson et al., 2023). GEM is a non-profit, scientific, public-private partnership that fosters global collaboration, developing transparent earthquake risk assessment resources for worldwide risk management. The most recent global seismic hazard map of PGA for a return period of 475 years can be consulted using an interactive online viewer (https://maps.openquake.org/map/gshm-2023-1/#5/15.216/-63.330) and is also available as GeoTIFF (https://cloud.openquake.org/s/6SnFk2f92JEr76H). The seismic hazard values of PGA from this database are indicated per island in Table 4-1.

Table 4-1 Seismic hazard values of PGA (in g) for a return period of 475 years. Source: GEM, Johnson et al. (2023).

Sint Maarten	Saba	Sint Eustatius	Aruba	Curaçao	Bonaire
0.26	0.28	0.29	0.13	0.04-0.05	0.02-0.03

5 Comparison of the PGA for 475 years

The three studies calculate the seismic hazard values for different return periods and hazard parameters. However, the seismic hazard of PGA for a return period of 475 years was calculated in all three. These values are plotted together in Figure 5-1. Generally, the values of Bozzoni et al. (2011) from the UWI-SRC are higher than those of Zimmerman et al. (2022). The values from GEM from Johnson et al. (2023) are sometimes higher and sometimes lower than those of Zimmerman et al. (2022). These deviations are due to the use of different criteria and assumptions in the models. All three model results are equally valid.

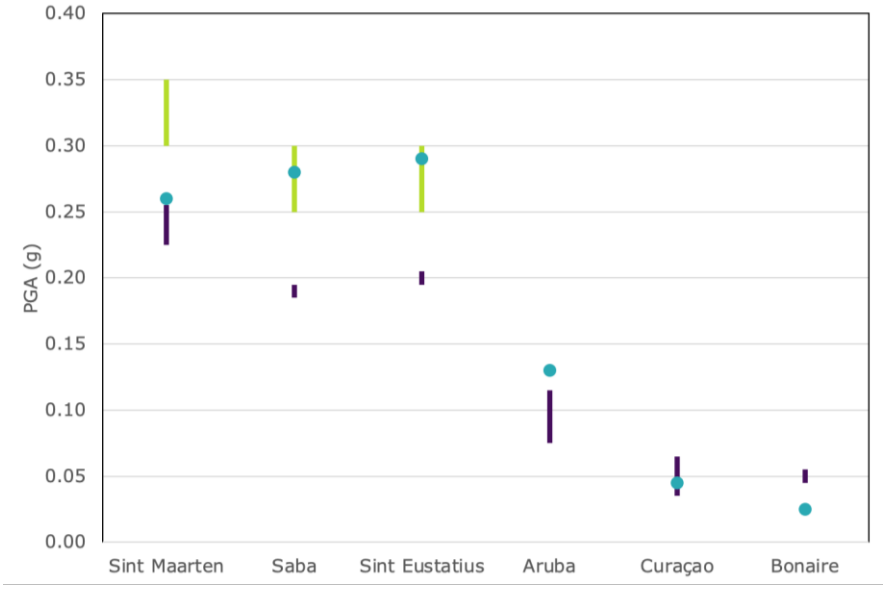

Figure 5-1 PGA values for a return period of 475 years from the three studies described in this report. The minimum and maximum value per island is indicated as a bar (green for the UWI-SRC/Bozzoni et al. (2011), purple for Zimmerman et al. (2022)). The aqua dots represent the values from GEM/Johnson et al. (2023).

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