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# EXECUTIVE SUMMARY

The probabilistic seismic risk assessment for the City of Port of Spain consisting of fourteen communities (hereafter referred to as Port of Spain) of the Republic of Trinidad and Tobago (hereafter referred to as Trinidad and Tobago) was undertaken as a part of the program Urban Disaster Resiliency and Preparedness in Trinidad and Tobago. The objectives of the assessment are to probabilistically estimate the expected risks of the buildings for structural damage, fatalities, and injuries for both daytime and nighttime scenarios, as well as internally displaced persons (IDPs) and debris volume that would result from an earthquake of seismic design level in Port of Spain.[i] These findings can contribute to the preparation of policies, plans, or training activities to reduce the social and economic impacts of future earthquakes on Port of Spain.

Table 0.1 summarizes the earthquake risks for Port of Spain, which the team estimated based on an average seismic intensity of .44g (Peak Ground Acceleration), including the site effect. The analysis showed that:

- The number of buildings that are expected to be yellow-tagged (indicating extensive to moderate damage) or red-tagged (complete damage or collapse) is estimated at about 9,400 structures, or approximately 63% of the building stock
- The damaged area of buildings is anticipated to be 3,814,000 m$^2$, which is about 43% of the total built area of buildings in the city
- Depending on the time of the event, approximately 370 to 520 fatalities (for an estimated rate of 0.8%) and 3,100 to 4,400 injuries (a rate of 7%) are anticipated
- The number of IDPs is anticipated to be about 23,100 immediately following the event, which comprises a large percentage of the population
- The expected volume of generated debris is 1,612,000 m$^3$, which is a significant quantity that the post-earthquake response plan must take into account

*Table 0.1: Expected risks of earthquake impacts for Port of Spain*

| Structural damage, m$^2$ (%) | Fatalities | | Injuries | | IDPs | Damage class tag | | Debris volume, m$^3$ |
|---|---|---|---|---|---|---|---|---|
| | Daytime, person (%) | Nighttime, person (%) | Daytime, person (%) | Nighttime, person (%) | Person (%) | Red, no. (%) | Yellow, no. (%) | |
| 3,814,000 (43%) | 520 (0.72%) | 370 (0.92%) | 4,400 (6.0%) | 3,100 (7.6%) | 23,100 (57.1%) | 5,500 (37%) | 3,900 (26%) | 1,612,000 |

The currently available research, geographical maps, seismic hazard, and building design guidelines served as the basis for identifying the design-level earthquake (with a 475-year return period) and the site conditions for Port of Spain, which the team used to set the seismic intensity for the probabilistic risk assessment. As part of the risk assessment, the project examined satellite imagery and conducted a buildings survey to collect data from a pool of representative buildings in Port of Spain.

Table 0.2 presents the exposure data for the study area extracted from the city census and building stock information of Port of Spain. The project team collected data and surveyed buildings, then used the data to divide buildings into various groups of similar construction types and evaluate the population distribution according to the census statistics. This approach formed the basis for the exposure model applied to the seismic risk analysis. For each building typology, the development of seismic fragility functions provided a representation of the damageability of each building type. The

[i] A seismic design level of earthquake intensity is applied to the entire area in this study. This design level is an approximation, as an actual earthquake's intensity will likely vary depending on the point of fault rupture.

consequence functions that correspond to each structural damage state (DS) for a given building type formed the final piece of input to estimate the amount of seismic impact assessed in this study (i.e., structural damage, fatalities, injuries, IDPs, and debris volume).

The project team then applied the input data to run impact simulations with the probabilistic analysis program for seismic risk estimation. The team conducted the seismic risk analysis for all building assets of the exposure model and accumulated the risk results of each building asset with respect to individual zones (primary and special zones), identifying the zones by land-use patterns and using them as the units of risk assessment in the study. Knowing the geographical distribution of seismic risk for individual zones is beneficial for government and city officials to plan resource allocation for seismic risk preparation and mitigation.

*Table 0.2: Exposure data for Port of Spain*

| No. of buildings | Built area, $m^2$ | Occupants (daytime)[ii] | Occupants (nighttime) |
|---|---|---|---|
| 15,060 | 8,778,000 | 72,800 | 40,400 |

Figure 0.1 presents the spatial distribution of the 5,500 red-tagged buildings (risk of complete damage or collapse) identified by the state of physical damage. There is a large concentration of red-tagged buildings in certain zones due to several factors, including the total number of buildings, seismic performance of buildings, earthquake intensity, and soil condition. Concerning the impact on people, Figure 0.2 shows the distribution of the expected fatalities in the daytime scenario (520 people) and identifies those zones classified as high-risk for human loss.

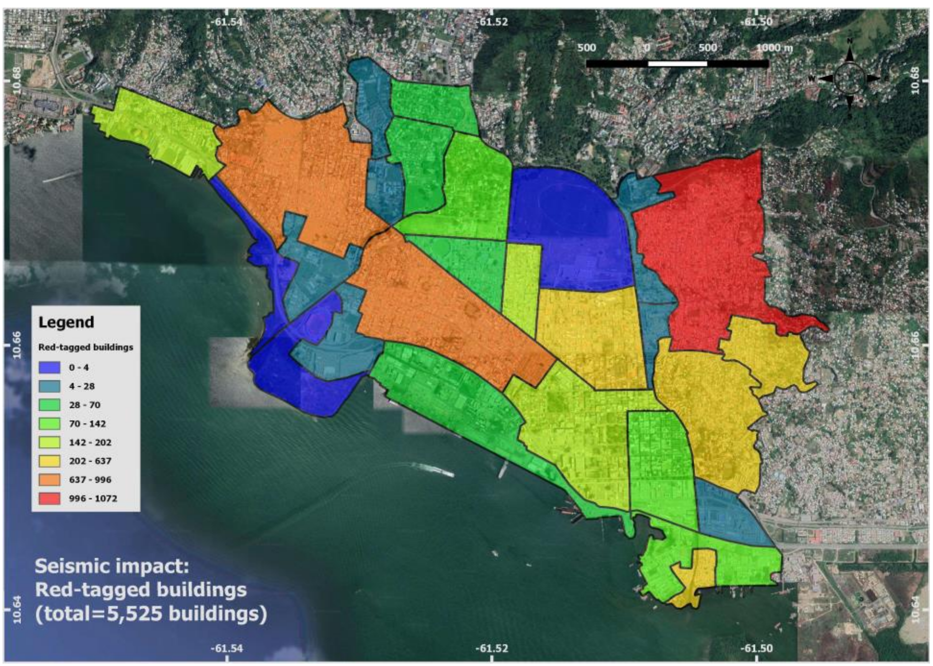


*Figure 0.1: Spatial distribution of red-tagged buildings*

[ii] The analysis considers people commuting to or visiting the study area from suburbs or outside the zone as daytime occupants.

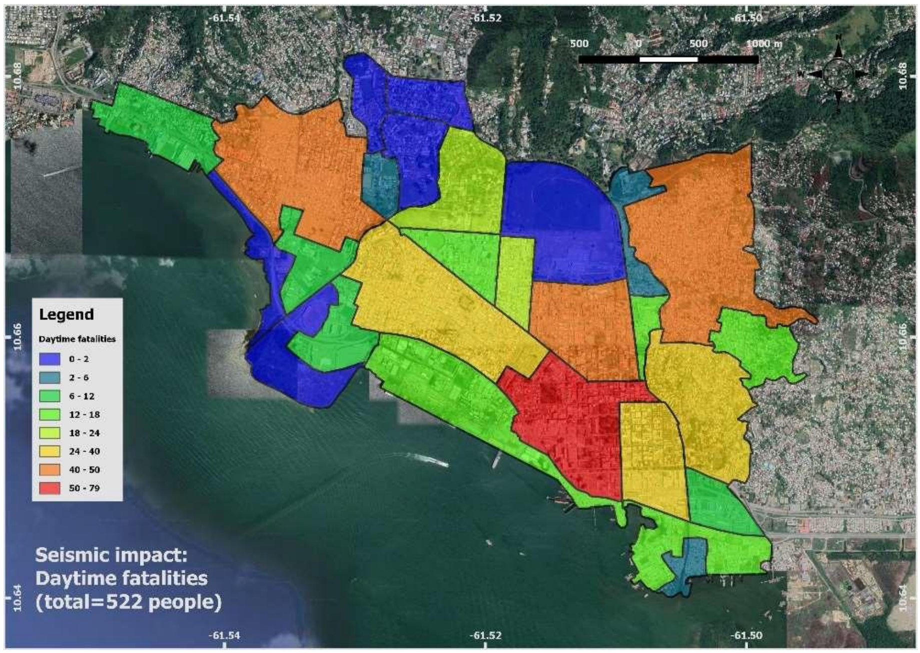


*Figure 0.2: Spatial distribution of daytime fatalities*

The significant physical damages, fatalities, and injuries predicted by this assessment stem from the large number of vulnerable buildings with unreinforced masonry or non-ductile construction types (e.g., old masonry wall buildings) and the moderate seismicity of the region. While the earthquake intensities applied to this study are at the seismic design level for Port of Spain and depend on the conditions of each location, the seismic risk assessment detects a relative vulnerability (in terms of physical damage and impact on humans) within the existing buildings in Port of Spain. The findings also highlight the need to develop a risk mitigation and preparation program. Based on the assessment findings, the project team recommends that such a program implement the following strategies:

- Provide a seismic strengthening program and prioritization strategy for key buildings identified during the analysis as having the highest seismic risk due to inherent structural vulnerability or density of occupants, offering their essential use during disaster events and recovery processes (e.g., in emergency response for government offices, hospitals, and schools)
- Establish a post-earthquake damage assessment program. It is critical to provide an original damage assessment logistic and to train and certify local engineers. Such a program will improve disaster response, recovery activities, and city resiliency following major earthquakes
- Optimize the allocation of emergency and response resources by identifying the most vulnerable zones with consideration to building damages and impacts on humans. It is necessary to prioritize the identified locations through an effective assignment of the limited resources
- Develop communication and public outreach programs regarding earthquake risks. Communities should be informed about potential earthquake risks, risk reduction methods, and response protocols (as outlined above)

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# 1 EARTHQUAKE HAZARD FOR PORT OF SPAIN

## 1.1 Overview

The project team based the earthquake hazard for this study on the seismic intensity, or peak ground acceleration (PGA), of a general design-level earthquake with a return period of 475 years for the case of Port of Spain. The design-level seismic intensity is appropriate for examining the seismic vulnerability of and expected damage to existing buildings in the city; it is generally used for new building design and is applied globally in modern seismic design. The team prepared the site PGA estimation by using the bedrock acceleration and surficial soil investigation data (site soil class) for Port of Spain to spatially estimate the acceleration at the ground level, considering the site amplification effect (i.e., the amplified PGA) as the ground shaking hazard for the risk analysis. In addition to the shaking hazard, Port of Spain is susceptible to liquefaction hazard due to earthquake, especially in coastal areas. The study considers the ground failure caused by liquefaction to be an earthquake liquefaction hazard.

## 1.2 Earthquake ground shaking hazard

### 1.2.1 Bedrock acceleration

The examination and comparison of several local and global seismic hazard studies identified the PGA intensity based on bedrock soil corresponding to the design-level earthquake for Port of Spain (SRC UWI and the European Centre for Training and Research in Earthquake Engineering [EUCENTRE] 2011; Global Seismic Hazard Assessment Program 1999; Bozzoni et al. 2011; GEM 2018). The seismicity in Port of Spain (i.e., the northern part of Trinidad) is high compared to other Eastern Caribbean islands. Figure 2.1 shows a seismic hazard map expressed with PGA intensities based on the bedrock soil conditions for Trinidad, which was the most recently studied data type for this area (SRC UWI and EUCENTRE 2011). During this research, estimations of the PGAs based on bedrock soil for the Eastern Caribbean region (10–19°N, 59–64°W) covered several return periods (95, 475, 975, and 2,475 years). The Eastern Caribbean region includes the Leeward Islands in the north (from Anguilla to Dominica), the Windward Islands in the south (from Martinique to Grenada), and Barbados and Trinidad and Tobago. The author states in the research document that the interplay and complexities between shallow crustal, intraplate, and interface subduction seismicity in the Caribbean region were thoroughly investigated. As illustrated in the hazard map shown in Figure 2.1, the PGA with the return period of 475 years for Port of Spain equals 0.325g according to this research and is a similar level as the earthquake intensities of the studies mentioned above. This seismic hazard study was conducted by focusing on the Eastern Caribbean region based on the latest local knowledge and data, and it is generally referred as the local seismic hazard. Also, the return period of 475 years is usually adopted as the design level earthquake intensity in the world. Therefore, this PGA value, 0.325g, is considered as the appropriate seismic intensity for this earthquake risk assessment.

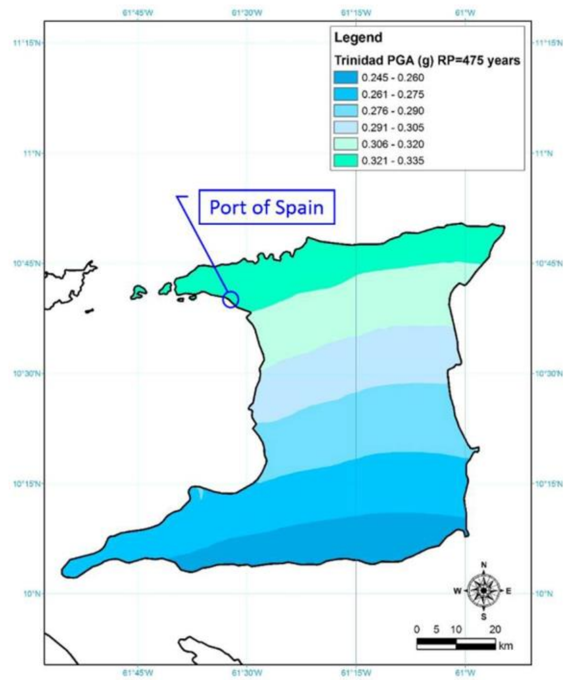


*Figure 2.1: Seismic hazard map of Port of Spain, Trinidad (SRC UWI and EUCENTRE 2011)*

### 1.2.2 Site soil class

The soil investigation study for Port of Spain referred to the SRC UWI (2018b) study, which categorized the sites in Port of Spain into several soil classes based on the microzonation studies and National Earthquake Hazards Reduction Program soil classification. The first map of Figure 2.2 shows the soil class distribution from this study, while the second map shows more detailed data on the shear-wave velocity of soil from the surface to a depth of 30 meters (i.e., Vs30). Based on the site soil classification of the microzonation report and the detailed Vs30 distribution, the project team identified the soil class of the target area of the study according to the soil class index of the American Society of Civil Engineers (ASCE) 7-16 building code (Table 2.1, ASCE 2017). The risk study for Port of Spain then adjusted the soil amplification factors specified in ASCE 7-16 for PGA with consideration of local soil characteristics in Port of Spain. The team opted to use this method because building code descriptions regarding soil amplification effects in Port of Spain are unavailable, and there is little research on amplification effects for PGA. Figure 2.3 shows the geographic evaluation of the site soil classes for Port of Spain based on the soil characteristics in Figure 2.2 and the classification indices in ASCE 7-16. The northern and eastern hillside areas are considered class B (rock), the immediate areas on the coastal side of class B sites are class C (very dense soil and soft rock), and the central part of the city and a part of the coastal area are class D (stiff soil). The western and southern coastal areas are class E (soft clay soil), assumed to be due to reclaimed land along the coastal side.

Clear information or documents regarding earthquake liquefaction damage in Port of Spain are unavailable. However, there is a possibility of seismic liquefaction at soft soil sites, such as the coastal areas of Port of Spain. In addition, the water table of the city is assumed to be at a depth of six to 26 feet in the study area (SRC UWI 2018b), which is not too deep to ignore the possibility of liquefaction. Therefore, the project team considers seismic liquefaction as one earthquake damage factor in this study (see Section 2.3), although there are insufficient historical data to determine the extent of potential liquefaction that could induce severe building damage in the area.

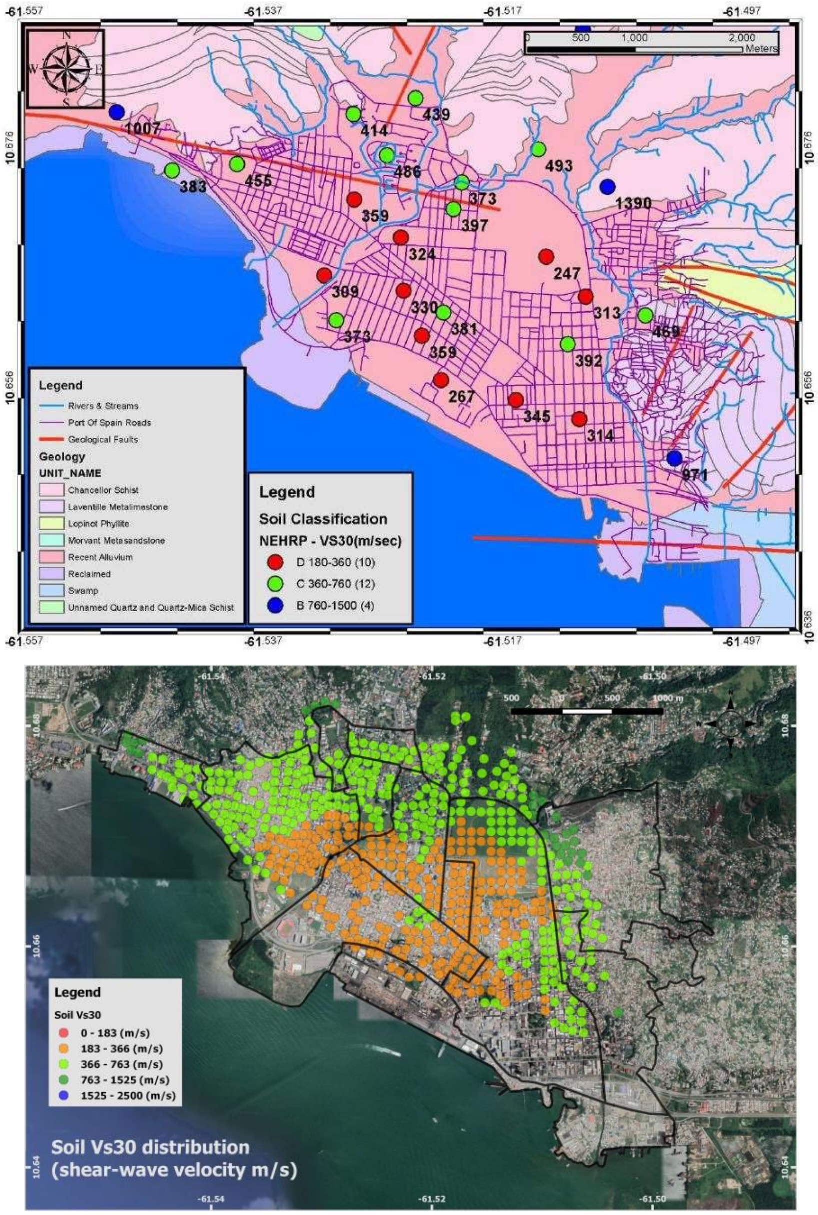


*Figure 2.2: Soil class identification for the Port of Spain area (SRC UWI 2018b)*

*Table 2.1. Soil class identification by the ASCE building code, ASCE 7-16 (ASCE 2017)*

| Soil class | Description |
|---|---|
| A | Hard rock, Vs30 > 1,525 m/s |
| B | Rock, Vs30 = 763 to 1,525 m/s |
| C | Very dense soil and soft rock, Vs30 = 366 to 763 m/s, N or Nch > 153 blows/m, Su > 96 kN/m$^2$ |
| D | Stiff soil, Vs30 = 183 to 366 m/s, N or Nch = 46 to 153 blows/m, Su = 48 to 96 kN/m$^2$ |
| E | Soft clay soil, Vs30 < 183 m/s, N or Nch < 46 blows/m, Su < 48 kN/m$^2$ |

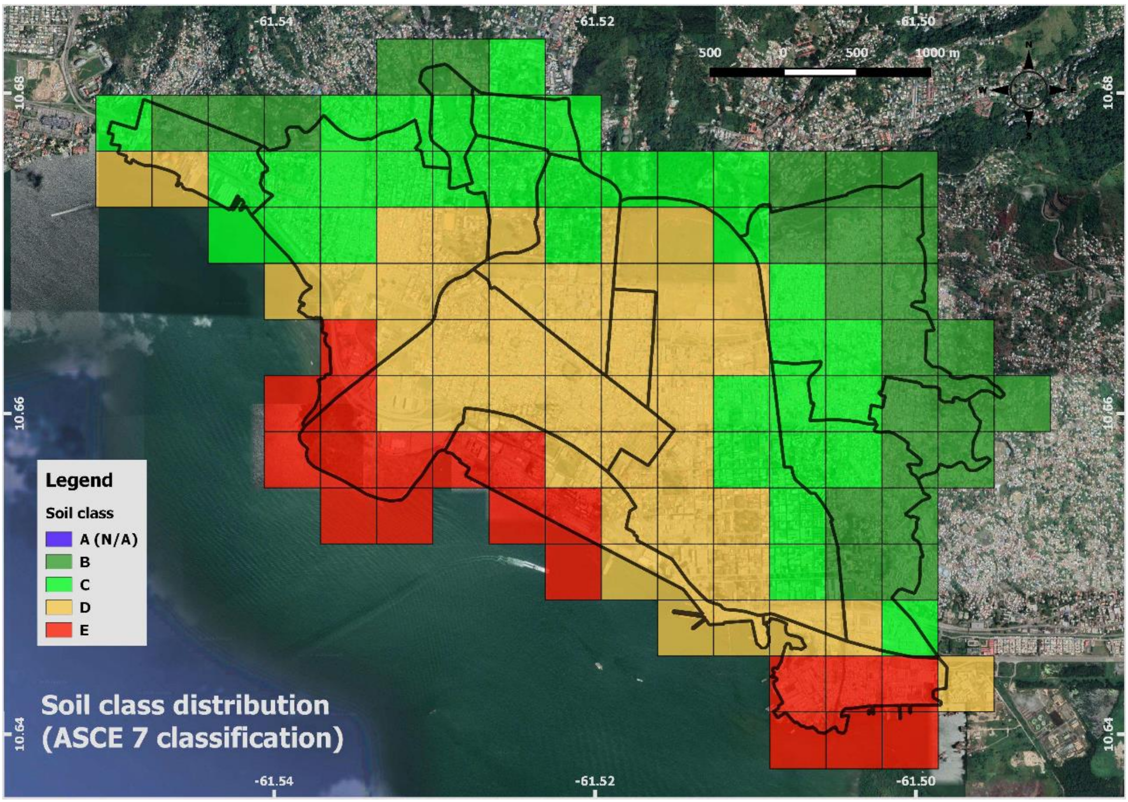


*Figure 2.3: Spatial distribution of site soil class for the study area*

### 1.2.3 Seismic design-level acceleration

This study developed site amplification factors for PGA (*FPGA*) by adjusting the ASCE 7-16 factors (ASCE 2017) with consideration to the local soil effects researched by SRC UWI (2018b) and Salazar et al. (2017). As shown in Figure 2.4, the site amplification factors are expressed according to the site class and the earthquake intensity (PGA in this study). For firm and rocky soil (i.e., class A and class B), no amplification due to surficial soil needs to be considered, placing the *FPGA* at approximately 1. For other soil types (i.e., softer soils), a certain level of amplification must be taken into account according to the earthquake intensity.

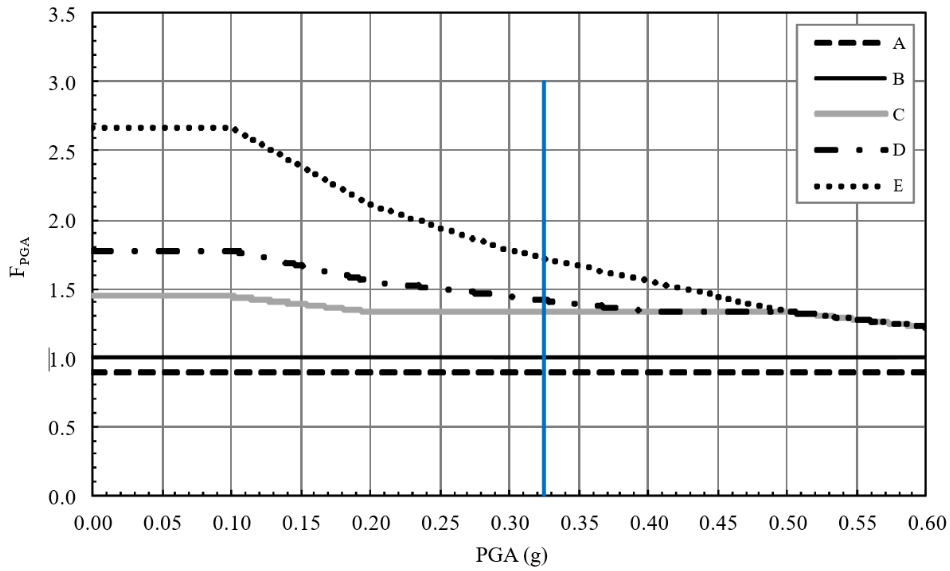


*Figure 2.4: PGA site amplification factor with adjusted ASCE 7-16 (ASCE 2017)*

As stated in Section 2.2.1, the PGA in Port of Spain based on the regional bedrock soil is equal to 0.325g, and the project team computed the $F_{PGA}$ based on this PGA intensity for each soil class (see Table 2.2). Thus the site-specific PGA for the design-level earthquake for Port of Spain would be from 0.33g to 0.56g, with consideration for soil amplification. Figure 2.5 presents a spatial distribution of the site-specific design PGA values for Port of Spain according to site soil class. The grid zone spacing of 0.0035 degrees (approximately 390 m) simplifies the PGA intensity distribution applied to the risk analysis.

*Table 2.2: $F_{PGA}$ for the study area by soil class*

| Site class | $F_{PGA}$ |
|---|---|
| A | 0.89 |
| B | 1.00 |
| C | 1.33 |
| D | 1.42 |
| E | 1.72 |