16th World Conference on Earthquake Engineering, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 4199 (Abstract ID)

Registration Code: S-K1463046111

Recommendations for improving the seismic code of Haiti

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Abstract

Haiti is a country with high seismic risk -due to the combination of high hazard and structural vulnerability- located on the Hispaniola Island, on the northern margin of the Caribbean plate. Its seismicity is mainly associated with two major faults that cross the island, with high slip rates located north and south respectively: Septentrional fault (12 mm/y) and Enriquillo fault (7 mm/y). Before the devastating earthquake on January 12, 2010, there was no building code in the country; neither seismic hazard studies had been developed. Some months after the earthquake, a first preliminary map of PGA was proposed by [1] and two years later new maps were presented as a result of developed detailed studies within the project SISMO-HAITI, funded by the UPM [2, 3]. These new maps were developed in terms of PGA and various spectral accelerations, SA (T), in order to make easier the direct construction of the uniform hazard spectra UHS for different return periods. In addition, some recommendations were also submitted to the governmental institutions aimed at proposing a specific building code for the country, after the analysis of other building codes of the region, as well as the Eurocode 8.

At present, the country has implemented a recommended building code [4] based on the map of [1] combined with the criteria of the International Building Code, IBC [5]

This paper makes a comparative analysis of: 1) the quoted maps with the hazard map of Dominican Republic and 2) the response spectra obtained by applying the current Dominican code, with the UHS derived in the frame of the SISMO-HAITI project. As a result, a number of recommendations are proposed to improve the seismic code of Haiti, if the responsible institutions consider it appropriate. The ultimate goal of this work is to help decrease the physical and social impact that future earthquakes may have in the country.

Keywords: Seismic hazard maps, Seismic code, Haiti.

1. Introduction

Haiti is located in the boundary of the Caribbean plate with the North-America plate, characterized by an active Rift of Caiman Islands with the biggest concentration of earthquakes in the region. Due to the activity of this boundary, together with a fault system crossing the Hispaniola Island (Haiti and Dominican Republic), Haiti has been affected by earthquakes with high magnitude in the past times, causing disaster in several cities (e.g. 1771, 1842, 1860, 1887).

The 12th January earthquake in 2010 was the most destructive event in modern times around the world in terms of people dead as percentage of the population of the country, according to the Inter-American Development Bank (BID). The physical and social impact was extremely high for the country.

The absence of significant seismicity in Haiti during the XX century contributed to the lack of awareness of the people about the seismic phenomenon, with the consequent lack of preparation to deal with it. When the 2010 earthquake occurred, Haiti did not have a seismic network or building regulations, so the structures were highly vulnerable and had very low resistance to the earthquake. The Mw 7 event caused a disproportionate number of breakdowns with the consequent physical and social disaster. As significant data worth to note: 300,000 buildings suffered severe damage or collapse; more than 300,000 people died; 350,000 were injured; and 1.3 million homeless, many of whom still live in precarious conditions.

The SISMO-Haiti project was conceived as a cooperation project funded by the UPM [2], taking, among other objectives, the estimation of seismic hazard for Haiti and characterization of the expected motion due to future earthquakes in order to establish a basis for a specific building code for the country, whose implementation will contribute to reduce vulnerability and risk. Results of such project and derivate work, [2], [3] where made widely public but they have not been implemented in practical solutions.

New earthquakes of Mw > 7 could be expected, particularly in the Enriquillo and Septentrional faults, involving risk in cities such as Port au Prince and Cap-Haitien. Therefore, preventive and mitigation measures are urgent in order to avoid catastrophes like the one suffered in 2010.

This paper presents a seismic hazard study developed in the frame of SISMO-HAITI project, together with the main conclusions and recommendations for the implementation of a Haitian Seismic code, trying to contribute to reducing the high seismic risk existing in the country.

2. Tectonic Framework

The Hispaniola Island is located in a transpresional boundary in which deformation is absorbed by a series of strike slip faults and compressive deformation zones. In Haiti, the deformation is essentially divided into two main transform areas with direction EW. To the north, the Septentrional fault absorbs approximately 12 mm/year [6,7]. To the south, the Enriquillo fault absorbs about 7 mm/year [6]. In addition, a compressive component is mostly absorbed by the subduction, but it is also transmitted partly into the Island. In the Septentrional fault only compressive deformation is absorbed, while in the area of the Enriquillo fault a series of reverse faults oriented WNW accommodate 2-3 mm/year [8]. Figure 1 shows the main tectonic units along with the seismicity of the area and the velocity field.

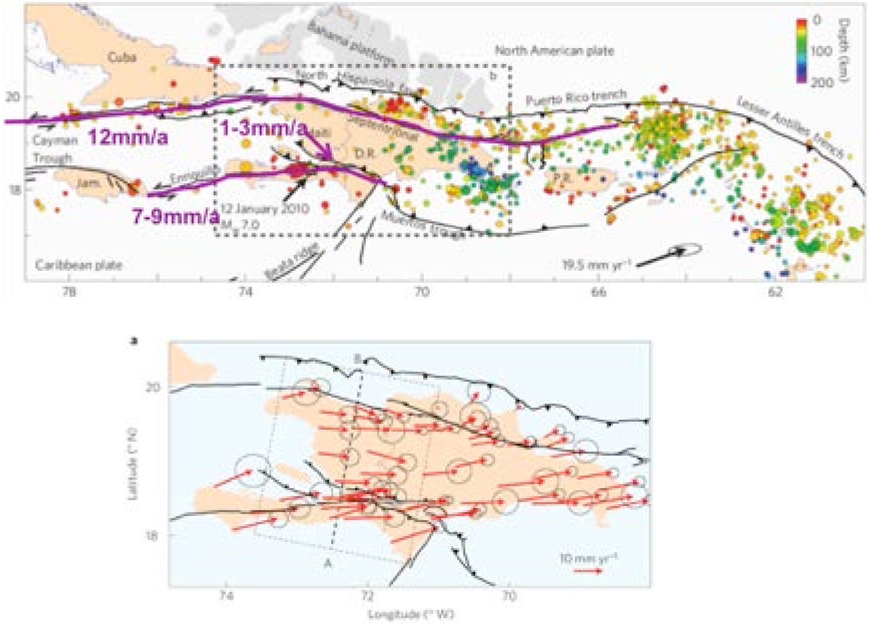

Figure 1. Up. Regional seismotectonic map. Down. Velocity with respect to the North American plate derived from GPS Observations [8]

3. Seismic Hazard Assessment

The hazard estimation has been carried out following the well-known Probabilistic Seismic Hazard Assessment method (PSHA, figure 2), considering a hybrid zoning model, which combines seismogenic zones and faults modeled as independent units. In a first step, the necessary inputs for hazard estimation have been prepared or identified 1) Seismic Catalogue, 2) Source Model and 3) Ground Motion Prediction Equations (GMPEs) or attenuation models. In order to quantify the epistemic uncertainty, a logic tree with two nodes, considering different options about recurrence models and GMPEs, has been adopted. The calculations have been made in terms of Peak Ground Acceleration, PGA, and spectral ordinates, SA (T), for T = 0.1, 0.2, 0.5, 1 and 2 seconds, and in all cases for return periods of 475, 975 and 2475 years.

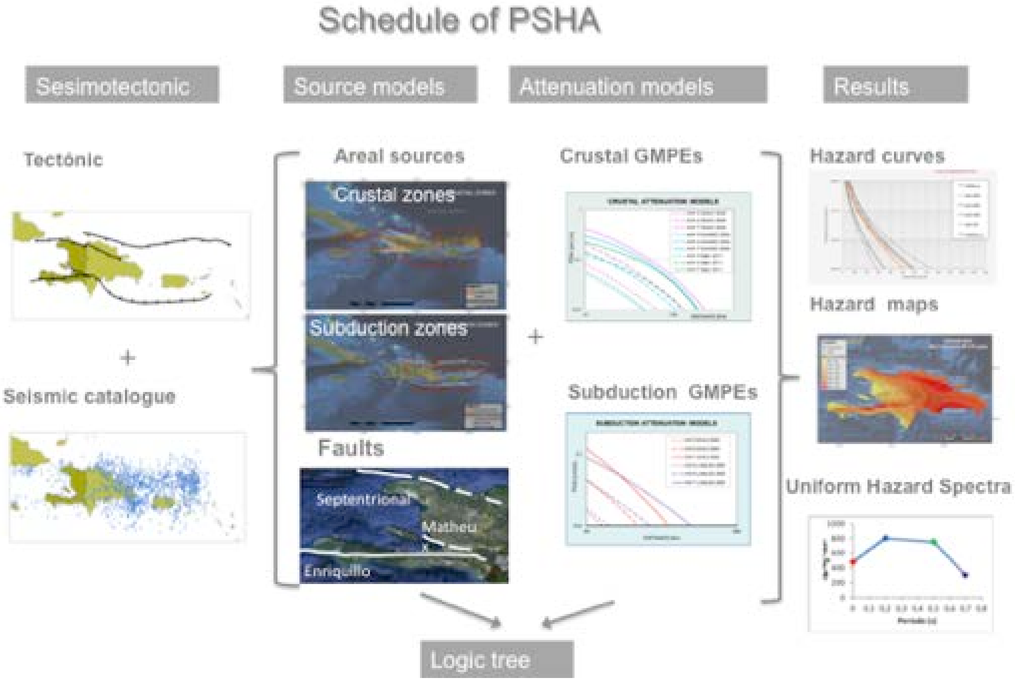

Figure 2. Scheme of the Seismic Hazard Methodology (PSHA) followed in the study.

3.1. Seismic Catalogue

The study started with the elaboration of a seismic catalogue for the Hispaniola Island, requiring an exhaustive revision of data reported by more than 20 seismic agencies. Most of the data was provided by the Puerto Rico Seismic Network (PRSN) and the Seismological Institute of Dominican Republic (ISDR), complemented with other data of international agencies such as USGS, NOAA, ISC, NRC, etc. The final catalogue contains 96 historical earthquakes and 1690 instrumental events, and it was homogenized to moment magnitude, Mw, adopting the empirical relations proposed in [9]. The catalogue was also depurated to remove aftershocks and foreshocks, as it is required by zoning methods, and was corrected of completeness for the estimation of the activity rate. Figure 3 shows the final catalogue and the epicenters of the biggest earthquakes in the region.

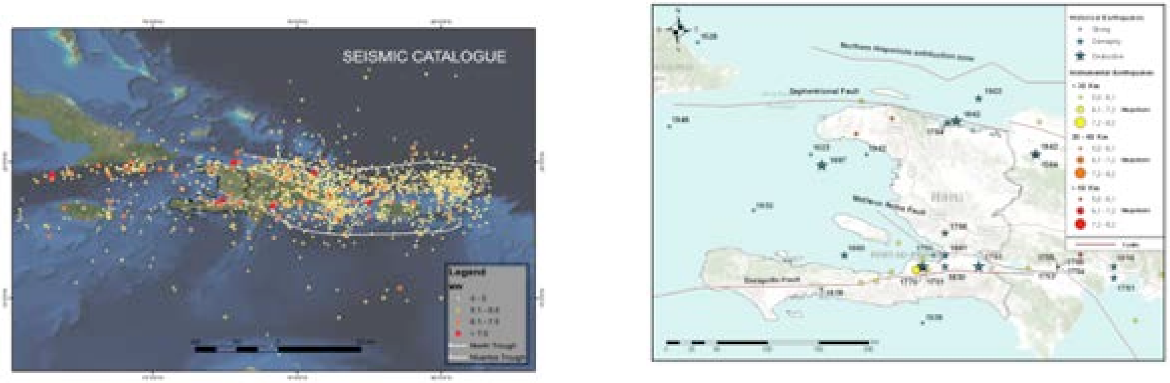

Figure 3. Left) Map of epicenters according with the final seismic catalogue of the project. Right) Epicenters of the biggest events affecting Haiti.

3.2. Seismic Zonation and source parameters

A model of seismogenic zones has been defined for the region, which has been combined with the three major faults modeled as independent units: Enriquillo, Septentrional and Matheux-Neiba Faults. The seismogenic zones were defined for the two tectonic regimens that converge in the region: crustal and subduction.

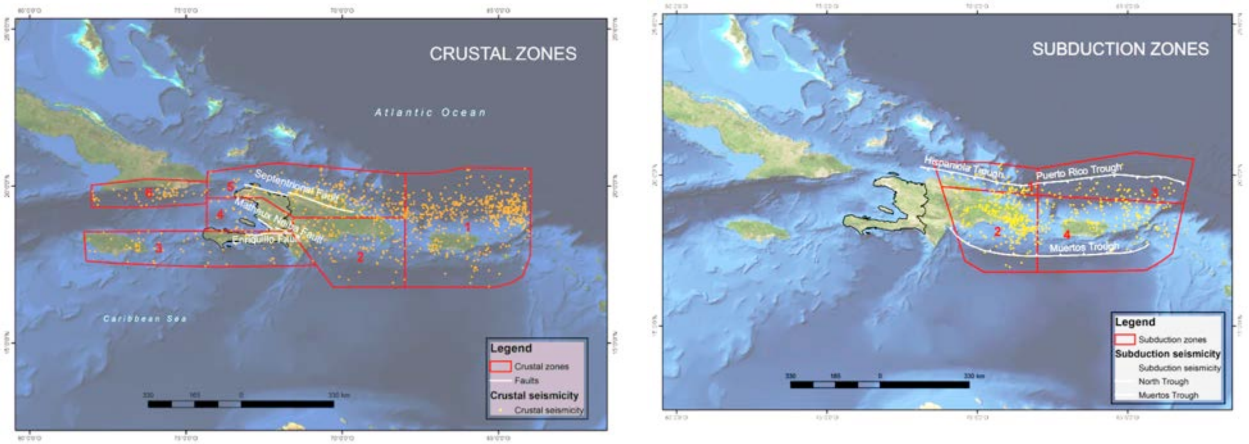

Figure 4. Seismogenic zones models. Left) Crustal zones with sallow seismicity. Righ) Subduction zones with depth seismicity.

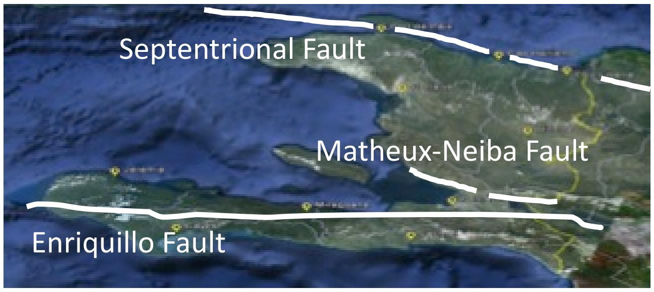

Figure 5. Faults considered as independent sources, combined with the seismogenic zones in the hazard estimation.

In the definition of the crustal zones, we have considered the following criteria: type of tectonic deformation, surface geology, homogeneity in families of quaternary faults (in terms of orientation, kinematics and size) and distribution and characteristics of seismicity. To define the subduction zones we have taken into account the geometry from geophysical data and the nature of the seismicity, through focal mechanisms. The zoning model defined is shown in Figure 4, and it contains 6 crustal zones and 4 subduction zones. The faults that are modeled as separate units are shown in Figure 5.

For the seismogenic zones, the recurrence models have been calculated through the Gutenberg-Richter law with data from the seismic catalogue, using the maximum likelihood method. For the maximum magnitude M_{max} of each zone, distributions of values ranging from the minimum value (M1) to the maximum value (M2) have been considered, taking the central value of the distribution as the most probable value, E(M). The minimum magnitude M_{min} for the estimation of the rate in each zone is $M_{min} = 4.0$. Table 1 presents these parameters.

Table 1. Seismic parameters of the seismogenic zones.

Crustal Zones

Zone	**Depth (km)**	**Mmax**			**Seismic parameters**	
		E (M)	M1	M2	b	N(M min)
Z 1c	10	7.8	7.5	8.0	1.01	18.79
Z 2c	10	8.0	7.7	8.2	0.87	4.19
Z 3c	10	6.6	6.3	6.8	0.74	2.56
Z 4c	10	6.7	6.4	6.9	0.81	0.97
Z 5c	10	7.3	7.0	7.5	0.92	9.51
Z 6c	10	7.4	7.1	7.6	0.91	2.75

Subduction zones

Zone	**Depth. (km)**	**Mmax**			**Seismic parameters**	
		E (M)	M1	M2	b	N(M min)
Z 1s	50-245	6.3	6.0	6.5	1.40	3.70
Z 2s	50-245	8.6	8.3	8.8	1.06	13.85
Z 3s	50-224	5.5	5.2	5.7	1.56	2.38
Z 4s	50-224	7.6	7.3	7.8	1.20	7.04

Note: M1 Minimun value of Mmax distribution; M2 Maximun value of Mmax distribution; E(M) expected value of Mmax; b Slope of Gutenberg-Richter law; N(Mmin) rate of number of events with Mw ≥ Mmin; being Mmin= 4.0

For the faults, two recurrence models have been considered: 1) characteristic earthquake model with Mc 7.7 for the Septentrional Fault, 7.6 for the Enriquillo Fault and 7.3 for Matheux-Neiba fault, and 2) Gutenberg-Richter model for those earthquakes with Mw higher than 6.5 associated to the faults, leaving the rest of the seismicity allocated to the seismogenic zones. In both cases, we have used the equations proposed in [10].

3.3. Ground Motion Prediction Equations, GMPE

As no GMPE have been developed for the region, we adopted the GMPE used for the most recent seismic hazard assessment developed for Central America [11, 12], given the similarities of the tectonics of both regions. For the same reason, we also included in our estimation other GMPE used in two seismic hazard studies carried out in the Caribbean: [9, 3]. The selected attenuation models and their main characteristics are shown in table 2.

Table 2. Ground Motion Prediction Equations selected for the study

GMPE	**TYPE OF SOURCES**	**ZONE DATA**	**TYPE MAG**	**MW RANGE**	**TYPE OF R**	**DISTANCE RANGE**
Kanno et al (2006) [13]	Intraplate crustal	Central America	Mw	4.0-9.0	Rrup	0-200 km
Zhao et al (2006) [14]	Intraplate inslab crustal	Japan	Mw	5-8.2	Rrup	10-300 km
Lin and Lee (2008) [15]	Intraplate inslab	Taiwan	Mw	5.3-8.1	R hypocentral	15-630 km
Atkinson and Boore (2011) [16]	crustal	World	Mw	5.0-8.0	R jb	< 200 km

3.4. Logic Tree

Two different recurrence models have been considered for the faults as two options in the calculations, as well as different combinations of GMPE for crustal and subduction zones. Therefore, we have adopted a logic tree composed by two nodes for the faults models and GMPEs alternatives. Figure 6 shows the logic tree, whose composition is as follows:

Node 1. Recurrence models for faults (both with weigh 0.5):

- Branch 1 (GR). Gutenberg- Richter model
- Branch 2 (CEM). Characteristic Earthquake Model, estimated from the slip rate obtained by GPS observations [8].

Node 2. Combination of GMPEs (crustal + subduction):

- Each branch combines a GMPE for the crustal zones and other for subduction, among the selected models given in Table 2. Highest weigh are given to branches containing to Atkinson and Boore model because it is the more recent and robust belonging to the Next Generation Attenuation (NGA).

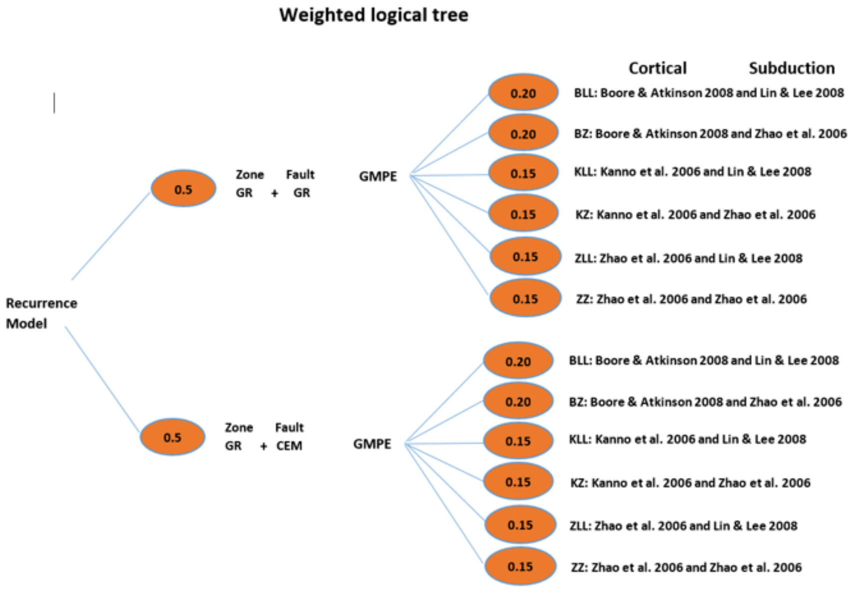

Figure 6. Logic tree adopted for the study

3.5. Results: Hazard maps and Uniform Hazard Spectra UHS

The seismic hazard estimations have been done with the software CRISIS [17] in a grid covering La Hispaniola Island, being the points equally separated 0.1º in longitude and latitude. The results have been interpolated to create the hazard maps in terms of PGA and several spectral ordinates SA (T), for different returns periods (RP) of 475, 975 and 2475 years. These maps represent weighted mean values of expected acceleration obtained with the combination of the different branches of the logic tree.

Figure 7 shows the map of PGA for RP 475, 974 and 2475 years. Other set of maps for spectral accelerations SA(T) in the range of T[0.1 to 2 s] have been obtained in the study. As example, Figure 8 show the map of SA (1s) for RP 475 yrs. It is important to mention that the maps of PGA for RP 475 and 975 years are used later for estimating the importance coefficients that will be recommended for the seismic code proposal.

Also, the Uniform Hazard Spectra (UHS) have been calculated in the main Haitian cities, for the three return periods analyzed. The UHS for RP 475 years in these cities are showed in figure 9.

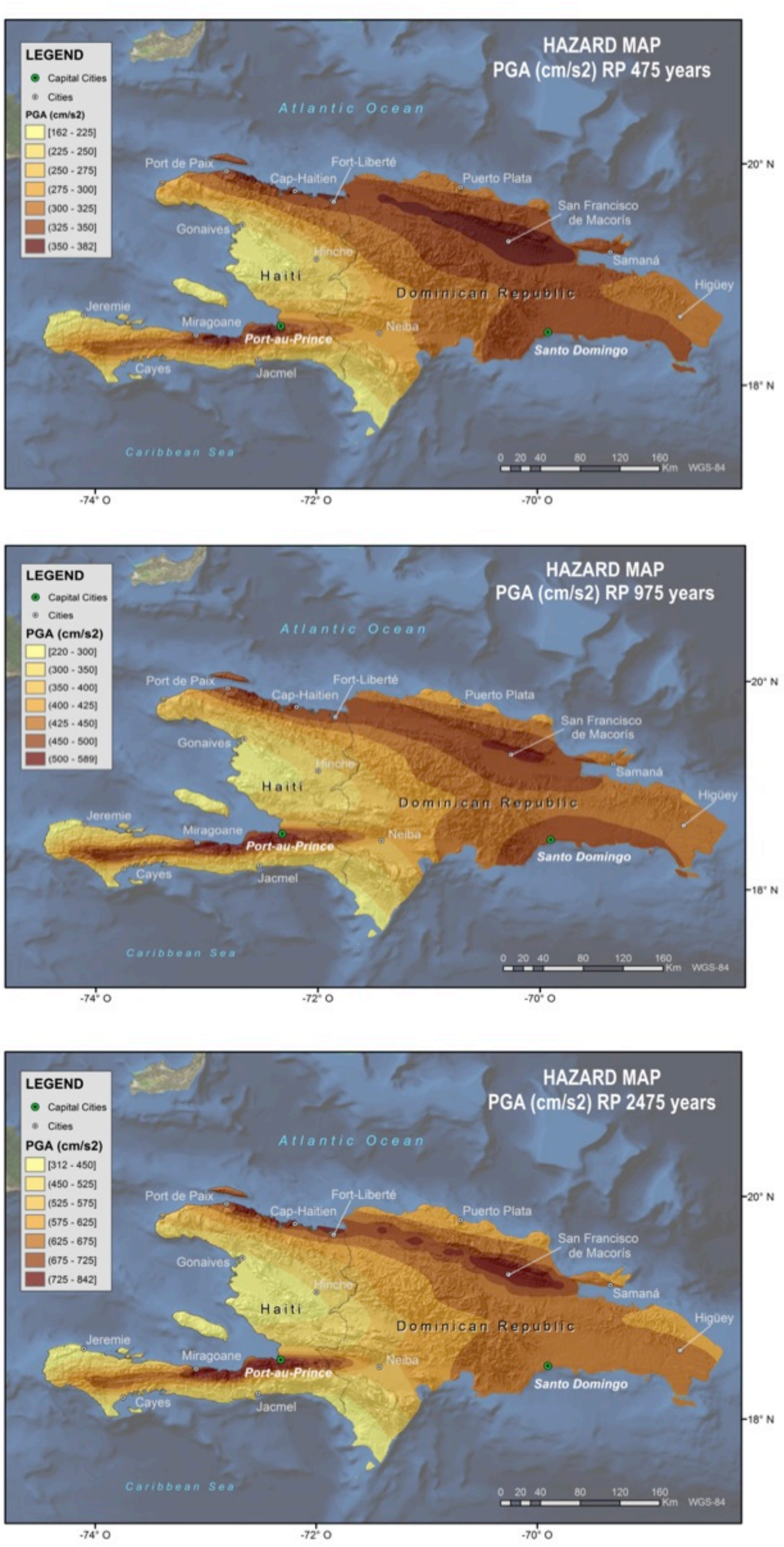

Figure 7. Results: hazard map in terms of PGA for Return Period PR of 475, 975 and 2475 years.

Figure 8. Results: hazard map in terms of SA(1s) for RP 45 years.

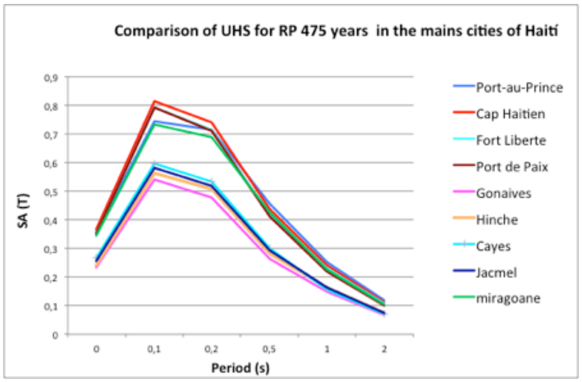

Figure 9. Results: UHS derived in the study for the main cities of Haiti. Spectral accelerations are given in g units.

4. Discussion of Hazard Results

The results obtained in this study have been compared with other precedent maps derived in previous works, in particular with the hazard map included in [1] and with the map of the Dominican Republic Code (DRC) [18]. These maps are represented in Figures 10 and 11, respectively. As result of the comparison we can conclude: 1) PGA values for RP 475 years obtained in this study are lower than the ones given in [1] for similar RP (10 % exceedance probability in 50 years), but the morphology of both maps is quite similar. 2) Our values are more consistent with the ones proposed by the DRC [18]

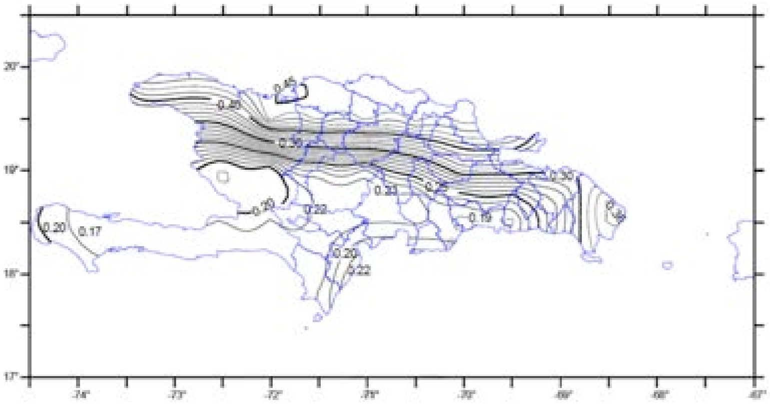

Figure 10. Hazard map of the Dominican Republic Seismic Code [17]. PGA (g) for return period of 475 years.

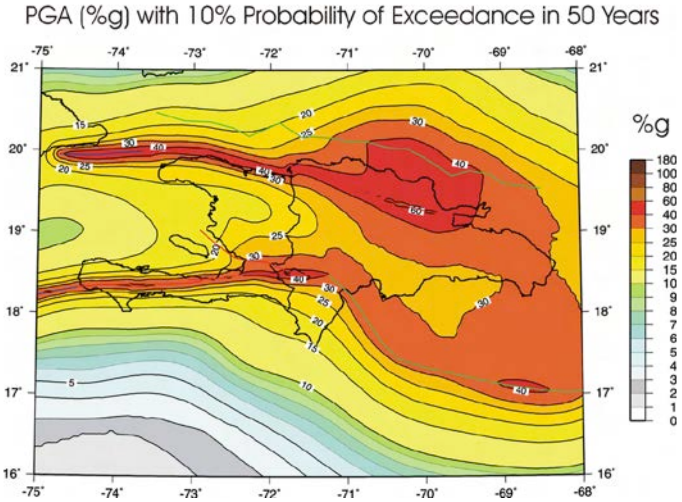

Figure 11. Hazard map of Frankel et al (2011)[1]. PGA (% g) for return period of 475 years.

Moreover, we have compared the UHS obtained in this study with the spectra resulting of anchorage the DRC spectral shape with the values here obtained for short and long structural periods. The regulation of DRC [18] is based on the IBC seismic code [5] and proposes coefficients Fa and Fv to scale the spectral shapes that are equivalent to the values of SA (0.2s) and SA (1s) for return period (RP) 2475 years, reduced by a factor 2/3. Both seismic codes, DRC and IBC, consider that the reduced spectra are comparable to those that would result for PR 475 years.

As an example, Figure 12 shows the result of the comparison of five types of spectra in Port-au-Prince: 1) UHS obtained in the study for RP 475 years, 2) UHS obtained for RP 975 years, 3) spectrum proposed by DRC equivalent of 2/3 SA (T) for RP 2475 years, 4) spectrum derived from spectral shape of DRC anchored with SA(T) for RP 475 years and 5) spectrum derived from spectral shape of Eurocode EC8 anchored with PGA for RP 475 years. As a result can be seen a better approximation between the spectra of cases 1 and 4 (involving the equivalence Sa DRC_475 ⇔ UHS_475) on the one hand; and the ones of cases 2 and 3 (which means 2/3 SaDRC_2475 ⇔ UHS_975) on the other hand. The spectra of EC 8 is intermediate among the others spectra. In conclusion, the spectra proposed by the DRC for 2475 years are closer to the UHS obtained in our study for PR 975 years , involving the following equivalence: $2/3\ SA(T)_{2475} \approx SA(T)_{975}$

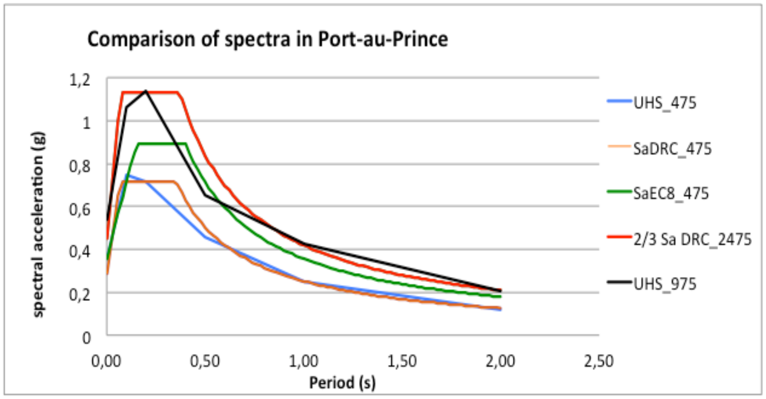

Figure 12. Comparison of the UHS obtained in this study for RP 475y. (in blue) and 975 y. (in black) with:

1) The spectrum proposed by DRC, equivalent to 2/3 SA(T) for PR 2475 years. (2/3Sa DRC_2475 in red).
2) The spectrum derived from DRC anchored with accelerations of RP 475 years (Sa DRC_475 in orange)
3) The spectral shape of EC8 anchored with the PGA of RP 475 years(Sa EC8_475 in green).

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Finally we have compared the accelerations derived in our study for RP 475 and 975 years, in order to obtain an estimate of the importance factor for different categories of building. To calibrate these coefficients, the map for RP 975 years is divided by the ones of RP 475 years. The ratio PGA 975 / PGA 475 at different points are shown in Figure 13 . These ratios provide a distribution of values whose average is 1.36, and the standard deviation is 0.04. Finally the importance factor recommended in this study for high risk building is 1.4

Figure 13. Map of the ratio PGA $_{975}$ / PGA $_{475}$ in different points. The values for the coefficients PGA $_{975}$ / PGA $_{475,}$ are mainly distributed in the range (1.3-1.5) and they represent the importance factor for different types of buildings.

5. Summary, conclusions and recommendations

We have conducted a study of seismic hazard in the Hispaniola Island in order to obtain criteria that contribute to the proposal for an own seismic code for Haiti. We have been followed for this purpose a Probabilistic Seismic Hazard Assessment method (PSHA), with the development of the following models of seismicity, zoning and perdiction equations (GMPEs):

- Seismic catalog data compiled from different agencies, including 1960 instrumental records and 96 historical events from 1522, homogenized with Mw where Mw [4.0-8.0].
- Model of seismogenic zones proposed from the existing tectonics and geophysical data, differentiating crustal (6 zones) and subduction regime (4 zones), whose recurrence models were estimated by adjusting the seismicity with a Gutenberg -Richter law. The ranges of variation of seismic parameters are:
  Crustal zones Mmax [6.6 – 8.0]; b [0.74 – 1.01], rate N (M min) [0.97-18.8]
  Subduction zones: Mmax [5.5. – 8.6]; b [1.06- – 1.56], rate N (M min) [2.3 – 13.8]
- Faults modeled as independent units in the hazard estimation:
  Enriquillo, with slip rate 7 mm/year and Mmax 7.6,
  Septentrional, with slip rate 12 mm/year and Mmax 7.7;
  Matheu-Neiba, with slip rate 1-3 mm/year and Mmax 7.3.
  The seismicity on faults have been modeled considering two alternatives: Gutenberg Richer (G –R) model and characteristic earthquake model (CEM).
- GMPEs proposed by [16] for cortical regime, [15] for subduction and [13, 14] for both.

The calculations have been made following a scheme of logical tree with two nodes, to consider the alternative options of the recurrence models on the faults and combination of GMPEs (crustal + subduction), estimating the peak acceleration PGA and spectral SA (T) for periods between 0.1 and 2 s, in all cases for RP 475, 975 and 2475 years. The principal results are summarized below:

- The values of PGA for RP of 475 years in Haiti range between 160 and 380 cm /s^2, being lower than the previous map of Frankel et al (2010) [1] and in the same order of magnitude as the values of the Dominican Republican seismic code (DRC). However the maps generated in this study have a similar morphology to the one of Frankel [1], although here they present lower values.

- The UHS have been obtained in the main cities of the country, resulting the highest UHS in the cities nearby the faults, with the values of SA (T) up to [799.55 - 430.46 cm / s^2] for T [0.1-0.5s]. The spectra proposed by the seismic code of Dominican Republic (DRC) correspond to RP 2475 reduced by a factor of 2/3 years and approximate the UHS obtained in our study for RP 975 years. Similarly the spectra proposed by the DRC correspond to RP 975 reduced by a factor of 2/3 years and approximate the UHS obtained in our study for RP 475 years. These results would be summarized as:
  2/3 SA(T) 2475 $\approx$ SA(T) 975; and 2/3 SA(T) 975 $\approx$ SA(T) 475

We have also analyzed the distribution of values PGA $_{975}$ / PGA $_{475}$ in order to determine the importance factor for different types of buildings. From the results we recommend the following classification and the amplification factors:

- Type I. Constructions negligible probability of its destruction by the earthquake may cause loss of life such as: Farm buildings, temporary buildings. Factor 0.9
- Type II. Normal occupancy buildings that can tolerate structural damage that make them inoperable as a result of a severe earthquake without collapse or partial collapse, not included in I, III and IV. Factor 1.0
- TYPE III. Buildings whose collapse could cause major human losses and significant economic impact, which must remain operational immediately after the occurrence of a severe earthquake, such as schools, hospitals, capacity more than 3000 people. Factor 1.2
- TYPE IV. High-risk buildings that should not suffer damage to structural and non-structural elements, during the occurrence of an extreme earthquake, in order to guarantee the integrity of the installation or building and protection of the population and the environment. Factor 1.4

With regard to soil classification and amplification factors, the study recommends to use the one proposed by the seismic code of the Dominican Republic, whose superficial geology is quite similar to that of Haiti. However, the factors should be calibrated by the microzoning studies conducted in the country.

It is worth to notice that, in spite of the explicit recommendation included in [1] to consider its hazard map as provisional until better information could be collected, the current building code in Haïti [2] maintains the hazard parameters from [1], without consideration of the information that was already provided in [2] and [3]. The study presented here was carried out in the frame of a cooperative line that several Spanish Universities and other foreign partners started with the Haitian government in 2010. Our results might contribute to define measures oriented to earthquake risk reduction in Haiti, which should be a real priority for national and international institutions. Authorities and society should be aware on the fact that the earthquake remains high in Haiti [8] and many of the populations are still affected by extremely high risk. A recent estimation of damage scenarios for Port-au-Prince and Cap-Haitien indicate that future possible earthquakes would leave almost 30,000 and 14,000 uninhabitable buildings [20] respectively, which represent about 50 % of the building stock of both cities. These results reveal that a new seismic catastrophe of similar or even greater consequences than the 2010 Haiti earthquake might happen if the earthquake resilience is not improved in the country [20].
We want also to point out that there exists a fragile connection between the scientific cooperative work and the country decision makers, which is preventing the projects to have a real impact in Haiti. All agents involved in the process —national authorities, scientists, international cooperation agencies - are in charge of changing this situation in order to guarantee the continuity of cooperation projects and its practical implementation, with the last and main purpose of avoiding futures disasters in the country.

Acknowledgments

This work has been carried out in the frame of SISMO-HAITI project, supported by the UPM. Additional contributions were coming from NORSAR (Norway), Global Earthquake Model (GEM), and Alicante and Almería Universities (Spain). Most part of the data for the seismic catalogue has been provided by the Puerto Rico Seismic Network (PRSN) and the

Seismological Institute of Dominican Republic (ISDR). Authors are grateful to these Institutions, and personally to Victor Huerfano, Eugenio Polanco, Julio García, Conrad Lindholm, Dominik Lang, Sergio Molina and Manuel Navarro.

6. References

[1] Frankel, A., Harmsen, C. Mueller, E. Calais and J. Haase (2011). Seismic Hazard Maps for Haiti. *Earthquake Spectra*, vol 27, S23-S24 pp

[2] Benito, B, Cervera, J., Molina, S., Navarro, M., et al. (2012). Report of the SISMO-HAITI project. *http://oa.upm.es/13999/.* Accessed 31 May 2016

[3] Pierristral, G., Benito, B, Cervera, J. (2012). Recomendaciones hacia la Normativa Sismorresistente de Haití. *Master Thesis.* http://oa.upm.es/22171/. Accessed 31 May 2016.

[4] Code National du Bâtiment d'Haïti 2012, Ministère des Travaux Publics Transports et Communications, Janvier 2013

[5] International Bulding Code, FEMA, P. (2009). NEHRP recommended seismic provisions for new buildings and other structures. *Building Seismic Safety Council of the National Institute of Building Sciences, FEMA.*

[6] Prentice, C.S., Mann, P., Pea, L.R. & Burr, G., (2003). Slip rate and earthquake recurrence along the central Septentrional fault, North American-Caribbean plate boundary, Dominican Republic. *Journal of Geophysical Research*, 108, doi:10.129/ 2001JB000442.

[7] Manaker, M., E. Calais, A. M. Freed, S. T. Ali, P. Przybylski, G. Mattioli, Jansma,C Prépetit y J. B. de Chabalier, (2008). Interseismic Plate coupling and strain partitioning in the Northeastern Caribbean, *Geophysical Journal International*, 174, 889–903.

[8] Calais, E., A. Freed, G. Mattioli, F. Amelung, S. Jónsson, P. Jansma, S. Hong, T Dixon, c. Prépetit and R Momplaisir, (2010). Transpressional rupture of an unmapped fault during the 2010 Haiti earthquake. Nat Geosci 3:794–799

[9] Bozzoni, F., M. Corigliano, G. Lai, W salazar, L. Scandella, E. Zuccolo, J. Latchman, L. Lynch and R. Robertson (2011). Probabilistic Seismic Hazard Assessment at the Eastern Caribbean Islands. Bull Seismol Soc Am vol 101, no. 5, pp. 2499-2521.

[10] Frankel, A., Mueller, C., Barnhard, T., Perkins, D., Leyendecker, E., Dickman, N., Hanson, S., and Hopper, M., 1996. National Seismic Hazard Maps: Documentation June (1996). USGS Open File Report 96 -532, U.S. Geol. Surv.

[11] Benito MB, Lindholm C, Camacho E, Climent Á, Marroquín G, Molina E, Rojas W, Talavera E, Escobar JJ, Alvarado G, Torres, Y. (2009). Amenaza sísmica en América Central. *Ed. Entimema*, Madrid 2009.

[12] Benito MB, Lindholm C, Camacho E, Climent Á, Marroquín G, Molina E, Rojas W, Escobar JJ, Talavera E, Alvarado GE, Torres Y. (2012). A new evaluation of seismic hazard for the Central America region. *Bull Seismol Soc Am* 2012 Apr 1;102(2):504-23.

[13] Kanno T, Narita A, Morikawa N, Fujirawa H, Fukushima (2006). *Bull Seismol Soc Am* 96:879–897.

[14] Zhao, J. X., J. Zhang, A. Asano, Y. Ohno, T. Oouchi, T. Takahashi, H. Ogawa, K. Irikura, H. K. Thio and P. G. Somerville (2006). Attenuation Relations Of Strong Ground Motion In Japan Using Site Classification Based On Predominant Period. *Bull Seismol Soc Am* vol. 96 (3), 898-913.

[15] Lin P‐S y Lee C‐T (2008). Ground‐motion attenuation relationships for subduction zone earthquakes in northeastern Taiwan. *Bull Seismol Soc Am* 98:220–240

[16] Atkinson, G. M., & Boore, D. M. (2011). Modifications to existing ground-motion prediction equations in light of new data. *Bull Seismol Soc Am*, 101(3), 1121-1135.
[17] CRISIS Ordaz, M., Aguilar, A., Arboleda, J. (2007). CRISIS2007. *National University of Mexico* (UNAM)

[18] Seismic Code of Dominican Republic: http://transparencia.mopc.gob.do/media/105304/R-001%20REGLAMENTO%20SISMICO.pdf. Accessed 31 May 2016.

[19] EN 1998-1:2004 (E). Eurocode 8, *Design of structures for earthquake resistance*, Part 1(General Rules)

[20] A first Approach to earthquake damage estimation in Haiti: advices to minimize the seismic risk. Y. Torres, S. Molina, S. Martínez-Cuevas, M. Navarro, J. J. Martínez-Díaz, B. Benito, J. J. Galiana-Merino & D. Belizaire. *Bulletin of Earthquake Engineering,* ISSN 1570-761X, Volume 14 ,Number 1, DOI 10.1007/s10518-015-9813-3.