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Seismic Risk Scenarios in Puerto Principe (Haiti). A Tool for Reconstruction and Emergency Planning

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1 Abstract

The 12 January 2010, an earthquake hit the city of Port-au-Prince, capital of Haiti. The earthquake reached a magnitude Mw 7.0 and the epicenter was located near the town of Léogâne, approximately 25 km west of the capital.

The earthquake occurred in the boundary region separating the Caribbean plate and the North American plate. This plate boundary is dominated by left-lateral strike slip motion and compression, and accommodates about 20 mm/y slip, with the Caribbean plate moving eastward with respect to the North American plate (DeMets et al., 2000). Initially the location and focal mechanism of the earthquake seemed to involve straightforward accommodation of oblique relative motion between the Caribbean and North American plates along the Enriquillo-Plantain Garden fault system (EPGFZ), however Hayes et al., (2010) combined seismological observations, geologic field data and space geodetic measurements to show that, instead, the rupture process involved slip on multiple faults. Besides, the authors showed that remaining shallow shear strain will be released in future surface-rupturing earthquakes on the EPGFZ.

In December 2010, a Spanish cooperation project financed by the Politechnical University of Madrid started with a clear objective: Evaluation of seismic hazard and risk in Haiti and its application to the seismic design, urban planning, emergency and resource management. One of the tasks of the project was devoted to vulnerability assessment of the current building stock and the estimation of seismic risk scenarios.

The study was carried out by following the capacity spectrum method as implemented in the software SELENA (Molina et al., 2010). The method requires a detailed classification of the building stock in predominant building typologies (according to the materials in the structure and walls, number of stories and age of construction) and the use of the building (residential, commercial, etc.). Later, the knowledge of the soil characteristics of the city and the simulation of a scenario earthquake will provide the seismic risk scenarios (damaged buildings).

The initial results of the study show that one of the highest sources of uncertainties comes from the difficulty of achieving a precise building typologies classification due to the craft construction without any regulations. Also it is observed that although the occurrence of big earthquakes usually helps to decrease the vulnerability of the cities due to the collapse of low quality buildings and the reconstruction of seismically designed buildings, in the case of Port-au-Prince the seismic risk in most of the districts remains high, showing very vulnerable areas. Therefore the local authorities have to drive their efforts towards the quality control of the new buildings, the reinforcement of the existing building stock, the establishment of seismic normatives and the development of emergency planning also through the education of the population.

2 Methodology.

For the seismic risk and loss assessment studies in Port-au-Prince (Haiti), the open-source software SELENA v5.0 (Molina et al., 2010, Molina *et al.*, 2007; Lang *et al.*, 2008) is applied (Figure 1). The software allows the use of deterministic, probabilistic and "real time"scenarios as the hazard on the study region (to calculate the seismic hazard input). According to the selected option, the seismic ground motion in each geographical unit is represented by soil-dependent response spectra which is derived through an empirical ground-motion prediction relation, spectral seismic hazard maps or real time shake maps, respectively. Physical damage probabilities (structural damage) are calculated by using the modified capacity spectrum method (MADRS) as given in FEMA 440 (FEMA, 2005).

Figure 1. Main layout of the SELENA web page (http://selena.sourceforge.net)

3 Seismicity in Haiti

Hispaniola Island lies along the complex boundary between the North American and Caribbean plates and is therefore subject to large, damaging earthquakes (Figure 2). The plate motion is partitioned between two offshore thrust systems, the North Hispaniola fault and the Muertos fault, and two major, strike-slip fault zones that bound the intervening Gonave microplate: the Septentrional fault zone (SFZ) on the north and the Enriquillo-Plantain Garden fault zone (EPGFZ) on the south (Prentice et al., 2010). The most last major earthquakes along the EPGFZ occurred in November 1751 (M ~ 7.5) and June 1770 (M ~ 8.0); both of them devastated Port-au-Prince. However the exact location of the related rupture has not been determined yet. Regarding the Septentrional Fault, the last major earthquake occurred in 1842 (M~8.0).
Additionally, as can be seen, the lack of instrumentation in Haiti has the consequence that the instrumental seismicity starts from 1950 aprox.. This is a weakness when seismic hazard in the region has to be evaluated and stress the importance of a political effort in the establishment of an operative Haitian Seismic Network.

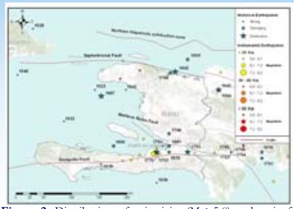

Figure 2. Distribution of seismicity (M >5.0) and main fault systems. Main historical earthquakes are represented with stars.

4 Building stock inventory and prevalent building typologies

During July 2011, a field campaign was carried out through the city with the cooperation of engineers from the ONEV. Therefore the building stock was classified in several building types according to their structure, main materials and use. Additionally the MTPCT (Ministère des Travaux Publics, Transports & Communications) provided us with a building database compiled after the 2010 earthquake containing structural information, damage state and use. Table 1 shows the defined model building types (MBT) in the city and the chosen vulnerability function (capacity and fragility curves; first ones are plotted in Figure 5). Finally, the building stock was classified according to the corresponding model building type and its location in the different districts (36 geounits) defined by the CNIGS .
As we can see from Figure 3a, the most of the building stock can be found included within the MBT: RC_UR (61%); CW (16%) and URC (15%). Therefore , although the computations will be done for all the MBT, we will focus in these prevalent buildings. Figure 3b shows, additionally, that the most of the building stock is used as Residential (88%). Figure 4 shows the prevalent building distribution at each district (geoounit).

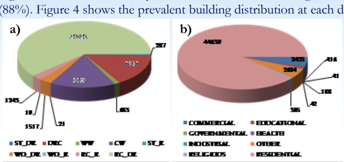

Figure3. a) Number of buildings classified according to the typologies defined for Port-au-Prince (See Table 1). **b)** Number of buildings classified according to their occupancy type.

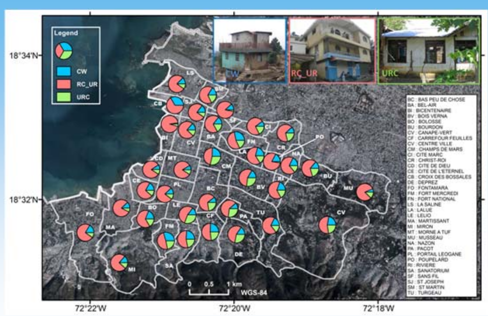

Figure 4. The city of Port-au-Prince was divided into 36 districts (geounits) and the damage is computed at the center of each geounit. The figure shows the name of the geounits, and the distribution of the prevalent typologies . Also a picture identifying the main characteristic of the typologies appears at the top.

Table 2 Building typology classification in the study areas of Port-au-Prince (Haiti) and allocation of vulnerability (capacity and fragility) functions used for the loss assessment

Label	Name, Description	Comparable with model building type defined by: HAZUS	RISK-UE	PAGER	Vulnerability functions assigned for the study
URC	Unreinforced concrete structure	URML	M11L	RS2	M1L-BTM (Lagomarsino and Giovinazzi, 2006)
RC.R	Reinforced concrete structure with reinforced concrete walls	C1L	RC1	C1L	RC1L-BTM (Lagomarsino and Giovinazzi, 2006)
RC.UR	Reinforced concrete structure with unreinforced masonry infill walls	C3L	RC1L	C3L	RC1L-pre (Risk-UE, Milutinovic and Trendafiloski 2003)
ST.R	Steel structure with reinforced concrete walls	S4	S4	S4	S4-pre (HAZUS, FEMA 2003)
ST.UR	Steel structure with unreinforced block masonry	S5	S3	S5	S5-pre (HAZUS, FEMA 2003)
WD.R	Wood structure with reinforced concrete walls	RM2	M4	RM2	M7-BTM (Lagomarsino and Giovinazzi, 2006)
WD.UR	Wood structure with unreinforced masonry	URML	M31	W1	M5wL-BTM(Lagomarsino and Giovinazzi, 2006)
WW	Confined wood walls with heavy bases	W1	n.a	W1	W1-pre (HAZUS, FEMA 2003)
CW	Confined or reinforced walls	URML	M4	M7	URML-pre (HAZUS, FEMA 2003)

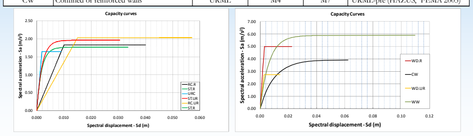

Figure 5. Capacity curves for the different model building types taken partly from *Lagomarsino and Giovinazzi* (2006), *HAZUS (FEMA*, 2003) and *RISK-UE (Milutinovic and Trendafiloski 2003).* (The corresponding fragility functions are not depicted.)

5 Damage scenario in Port-au-Prince (Haiti)

In order to predict the damage scenarios for the current building stock of Puerto Principe we have taken into consideration two possible assumptions (Dr. J. Martinez, *pers. comm.*): the maximum earthquake happening in the Enriquillo Plantain Garden fault zone (Dumay scenario) and the most probable earthquake happening in the Muertos-Neiba-Matheaux fault system (Neiba scenario). In both cases the soil-dependent response spectra at each geounit was obtained through the ground-motion prediction equation given by NGA relation (Boore and Atkinson, 2008). Soil amplification was included in the NGA relation using the Vs30. This parameter was previously obtained through a microzonation study that the Haiti working group carried out during July 2011 (Dr. M. Navarro, *pers. comm.*).

Figure 6. Vs30 distribution in the city of Port-au-Prince and chosen earthquake scenarios. As expected, the deepest sediments (lower Vs) appears close to the coastline.

Figure 7. Complete Damage distribution in the city of Port-au-Prince for a) Neiba scenario and b) Dumay Scenario. Damage is shown as percentage of the total building stock at each geounit. Aditionally a color scale represent the PGA in units of g's.

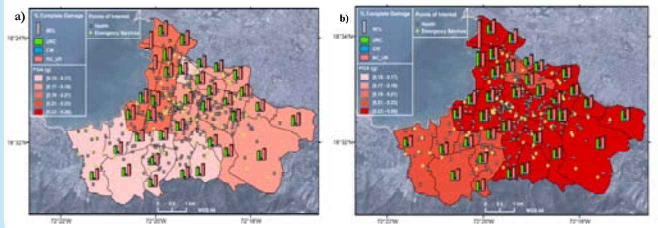

Figure 6 shows the seismic scenarios and the Vs30 distribution for each one of the geounits. Uncertainty has been included assuming that the ground motion can be represented by Boore and Atkinson NGA (weigthed 0.70 and $\pm$ 1 standard deviation (weigthed 0.15 each). Therefore, that logic tree can provide median results and corresponding uncertaintiy in terms of standard deviation (Table 2).

Figure 7 shows the comparison between the complete damage produced by both scenarios. Additionally, the PGA (in terms of g's) for the median ground motion relationship has been displayed as a ground color scale. It's easy to see how the ground motion is amplified on those geounits with a lower Vs30. These geounits are the most distant from the rupture area of the earthquake so ground motion is not very different from the closest geounits (hgih Vs velocity). The damage is uniformly distributed along the city so the building distribuiton with complete damage can be found on all geounits, maybe slightly higher on those with a higher Vs. In any case these results point out the high vulnerability of the current building stock to a new occurrence of a big earthquake.
Table 2 summarizes the damage results accumulated for all the city as a median $\pm$standard deviation value. Results have been included not only for the prevalent building types (RC_UR, URC and CW) but also for those typologies over the 2% of the total building stock (WD_UR, RC_R). We can see as the URC typolgy shows the highest vulnerabilty. Additionally, all the health and emergency facilities in the city are distributed in geounits with an important number of damaged buildings. Finally we can establish that independently of the chosen scenario (Dumay or Neiba) the complete damage will range from 27% to 34% of the total building stock and that between 65% and 72% of the total building stock will suffer at least slight damage, stressing the importance of emergency planning, seismically designed new constructions and reinforcement plans.

Table 2. Comparison of structural damage for the chosen earthquake scenarios.

Damage State	Earthquake Scenario	Number of buildings [1] ± standard deviation: RC_UR	URC	CW	WD_UR	RC_R	TOTAL[2]
Slight	Dumay	3557 ± 423	1014 ± 156	1767 ± 241	221 ± 32	264 ± 49	7061 ± 876 **(14%)**
	Neiba	3810 ± 265	1087 ± 71	1866 ± 112	235 ± 5	288 ± 27	7471 ± 418 **(15%)**
Moderate	Dumay	4159 ± 254	1053 ± 81	2181 ± 225	197 ± 14	108 ± 12	7837 ± 410 **(15%)**
	Neiba	4229 ± 116	1042 ± 36	1954 ± 316	190 ± 11	107 ± 9	7607 ± 421 **(15%)**
Extensive	Dumay	2164 ± 74	659 ± 36	1212 ± 393	133 ± 10	150 ± 18	4358 ± 475 **(9%)**
	Neiba	2108 ± 94	611 ± 54	886 ± 315	121 ± 13	138 ± 18	3881 ± 500 **(8%)**
Complete	Dumay	12798 ± 2679	2698 ± 940	622 ± 461	450 ± 187	424 ± 165	17010 ±4432 **(34%)**
	Neiba	10835 ± 2130	2020 ± 635	335 ± 209	310 ± 75	302 ± 121	13811 ± 3170 **(27%)**

[1] Only for prevalent buildings (>2% of the total building stock (N): 50768 buildings)
[2] Accumulated for all building typologies (also those with a stock lower than 2% of N).

6 Outlook and further procedure

The obtained results have been computed using a very basic model building type distribution derived from survey estimation and existing databases. The following conclusions can be proposed:

a) The existing building stock still shows a high vulnerability therefore, the maximum expected earthquake (Dumay) or the most probable earthquake (Neiba) will strongly affect the city causing between 35% to 43% of buildings with at least extensive damage.
b) The damage distribution along the city is quite uniform due to the site effect amplification on the distant geounits and the higher ground motion in the closest geounits. If we also take into consideration that emergency buildings and health care buildings are also spread on the city, then it will increase the difficulty of emergency management within the city. Wounded population will have to be displaced outside the city .
c) Finally, this study will be continued with a compilation of more detailed information on distribution of the population on the study area and cost of repair/replacement in order to apply a detailed human and economic losses model.

The Haiti working group:

Authors are only part of a multidisciplinary team of scientist working on the seismic risk management of Haiti. The rest of the team is: Dr. M. Navarro (Univ. Almeria), Dr J. Martinez-Díaz and Dr. D. Córdoba (Univ. Comp. Madrid), Dr. M.A. de las Doblas (CSIC), Dr. D. Belizaire (ONEV-Haiti) and the Earthquake Engineering Group (Univ. Politécnica Madrid- http://www2.topografia.upm.es/grupos/sismo/).

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