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PROBABILISTIC SEISMIC HAZARD ASSESSMENT IN QUITO CITY, ESTIMATES AND UNCERTAINTIES

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CONTEXT

The present study is focused on estimating the probabilistic seismic hazard for the capital city of Ecuador, Quito, with more than 2 millions inhabitants at present. Quito is located at 2800m a.s.l. within the Interandean Depression, bounded by the equatorial line to the north, in an earthquake-prone environment. The city and its suburbs have developed on a piggy-back basin on the hanging wall of a reverse fault system, which has been recognized as active by historical, geomorphologic, geological and geodetic studies (Ego and Sebrier 1996, Hibsch et al. 1997, Alvarado et al. 2014). The historical record, spanning 5 centuries, shows that the city experienced at least five times intensities in the range VII to VIII, with damages reported in churches and houses (Egred 2009). In an attempt to extend the observation time window, Hibsch et al. (1997) analyzed earthquake-induced deformation phenomena in lacustrine sediments in the northern part of the Quito basin, one major event was identified (intensity evaluated to X, higher than the maximum intensity in the historical record) between the 10th and the 16th centuries, which they believed could have ruptured the entire Quito fault reaching a magnitude 6.5-7.0. This is the unique evidence for such a large earthquake on the fault system. More recently, the seismic potential of the Quito fault was confirmed on the basis of observations covering a much shorter time window. Analyzing GPS measurements at sites with 10 to 15 years of recordings, east-west horizontal shortening rates were estimated in the range 4.3 to 5.3mm/yr across this blind thrust (Alvarado et al. in 2014).

SEISMIC HAZARD ESTIMATES

Probabilistic seismic hazard estimates at 475 years return period are provided for Quito. The results show that the crustal host zone is the only source zone that is really impacting the hazard levels in Quito for such return period. Therefore, the emphasis is put on identifying the uncertainties characterizing the host zone, i.e. uncertainties on the recurrence of earthquakes expected in the zone and uncertainties on the ground motions that these earthquakes may produce. As the number of local strong-ground motions is still scant, ground-motion prediction equations are imported from other regions. Rather than sampling a complex logic tree, several plausible models are considered and associated to the corresponding uniform hazard spectra.

Exploring recurrence models for the host zone based on different observations and assumptions, and including three GMPE candidates (Akkar and Bommer 2010, Zhao et al. 2006, Boore and Atkinson 2008), we obtain a significant variability on the estimated acceleration at 475 years:

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- Considering historical earthquake catalogs, and relying on frequency-magnitude distributions where rates for magnitudes 6-7 are extrapolated from statistics of magnitudes 4.5-6.0 mostly in the 20th century, the acceleration at the PGA varies between 0.28 and 0.55g with a mean value around 0.4g. The results show that both the uncertainties on the GMPE choice and on the seismicity model are responsible for this variability.
- Considering slip rates inferred form geodetic measurements across the Quito fault system, and assuming that most of the deformation occurs seismically (conservative hypothesis), leads to a much higher range of accelerations, 0.43 to 0.73g for the PGA (with a mean of 0.55g).
- Considering slip rates inferred form geodetic measurements, and assuming that 50% only of the deformation is released in earthquakes (partially locked fault), leads to a range of accelerations 0.32 to 0.58g for the PGA, with a mean of 0.42g. These accelerations are in agreement with the catalog-based hazard estimates.
- If restricting the occurrence of magnitudes 6 to 7 to the Quito fault (a simplified geometry), and applying GMPEs including a hanging-wall coefficient (Abrahamson and Silva 2008, Chiou and Youngs 2008), the hazard increases up to 40% at sites located above the fault plane.

Based on these different calculations, we conclude that 0.3g should be considered as a strict minimum bound for the peak ground acceleration at 475 years return period for the city of Quito. If modeling the recurrence based on the past earthquake catalog, as in most probabilistic seismic hazard studies in the world, the mean value obtained is around 0.4g. Keeping in mind that these values are for a site at rock, and that site effects need to be further taken into account, we propose that 0.4g be considered as the reference value for the PGA at 475 years in Quito. Higher acceleration values have been obtained in various exercises based on rather conservative assumptions, underlying the large uncertainty on the hazard and stressing that the seismic hazard in Quito must be handled with great caution.

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