NEW GROUND MOTION PREDICTION EQUATION FOR DEEP SUBDUCTION EARTHQUAKES IN COLOMBIA

C.A. Arteta 1, C. Lozano 2, A. Ojeda 3 and C. Pajaro 4

ABSTRACT

Two deep large earthquakes with Mw = 7.2 and 7.0 occurred in Colombia (Northern South America) in 2012 and 2013, which made evident the vast potential of damage to vulnerable towns near the epicenters. As a contribution to the update of the seismic hazard of Colombia, a preliminary evaluation of the relationship between magnitude, distance, soil type and spectral acceleration at different periods was assessed with the objective of developing prediction models for ground motions from deep subduction earthquakes in the Pacific and Western Region of Northern South America. This article presents advances in the determination of a ground motion prediction equation that uses 249 records from 19 deep subduction events with Mw > 4.9, depth larger than 70 km, hypocentral distance shorter than 500 km, located in Colombia between 0° - 6° latitude North and 79° - 75° longitude West. These ground motions, associated to the subduction of the Nazca plate in the Colombian Western region, were recorded in rock and soil sites by the National Strong Motion Network of Colombia. The residual analysis based on a global ground motion prediction model known as the BC Hydro GMPE, suggested the need for a regional ground motion prediction model that accounts for differences in hypocentral distance scaling, in order to completely explain the empirical data of the deep subduction earthquakes in the Western region of Colombia. A new model for the prediction of ROTD50 five-percent-damped spectral acceleration intensity values for intraslab subduction earthquakes is presented. The model is a regionalization of the global BC Hydro Model, from which the magnitude scaling terms are used. A regression process, including random effects, resolves the coefficients of the selected functional form, which also includes a fore/back arc, hypocentral depth, and soil terms, along with the typical regional magnitude and distance scaling terms. Analysis of the residual show an improved agreement with the recorded empirical data, hence the model is deemed appropriate to estimate ground motions from deep subduction events in Northern South America.

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New Ground Motion Prediction Equation for Deep Subduction Earthquakes in Colombia

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ABSTRACT

Two deep large earthquakes with Mw = 7.2 and 7.0 occurred in Colombia (Northern South America) in 2012 and 2013, which made evident the vast potential of damage to vulnerable towns near the epicenters. As a contribution to the update of the seismic hazard of Colombia, a preliminary evaluation of the relationship between magnitude, distance, soil type and spectral acceleration at different periods was assessed with the objective of developing prediction models for ground motions from deep subduction earthquakes in the Pacific and Western Region of Northern South America. This article presents advances in the determination of a ground motion prediction equation that uses 249 records from 19 deep subduction events with Mw > 4.9, depth larger than 70 km, hypocentral distance shorter than 500 km, located in Colombia between 0° - 6° latitude North and 79° - 75° longitude West. These ground motions, associated to the subduction of the Nazca plate in the Colombian Western region, were recorded in rock and soil sites by the National Strong Motion Network of Colombia. The residual analysis based on a global ground motion prediction model known as the BC Hydro GMPE, suggested the need for a regional ground motion prediction model that accounts for differences in hypocentral distance scaling, in order to completely explain the empirical data of the deep subduction earthquakes in the Western region of Colombia. A new model for the prediction of ROTD50 five-percent-damped spectral acceleration intensity values for intraslab subduction earthquakes is presented. The model is a regionalization of the global BC Hydro Model, from which the magnitude scaling terms are used. A regression process, including random effects, resolves the coefficients of the selected functional form, which also includes a fore/back arc, hypocentral depth, and soil terms, along with the typical regional magnitude and distance scaling terms. Analysis of the residual show an improved agreement with the recorded empirical data, hence the model is deemed appropriate to estimate ground motions from deep subduction events in Northern South America.

Introduction

Within any seismic hazard analysis, a ground motion prediction equation (GMPE), formerly known as attenuation relationship, is used to estimate the ground motion of interest ([1-5]). The development of a GMPE is not a simple curve fitting regression process, because this will make the developed equations only valid within the empirical data span. To overcome this limit, the development of a GMPE consists of a statistical model based on seismological and geotechnical

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theories with the purpose of making extrapolations valid. In this paper, we present the main advances in the development of a GMPE for deep subduction intraslab events in Colombia. Examples of intraslab events recently recorded in the region are: (i) the 6.3 Mw earthquake in Calima (Valle) in 1995 (Latitude 4.439, Longitude -75.698, Depth 207 km); (ii) the 6.7 Mw earthquake in Génova (Quindio) in 1997 (Latitude 4.768, Longitude -77.724, Depth 230 km); (iii) the 7.1 Mw earthquake at La Vega (Cauca) in 2013 (Latitude 1.973, Longitude -76.558, Depth 172 km); and (iv) the Guaitarilla (Nariño) Earthquake in 2013 with moment magnitude of 7.0 (Latitude 1.113, Longitude -77.561, Depth 163 km).

In Colombia, there are just a few attenuation models to estimate ground-motion intensities. Recordings for attenuation model development are gathered from the National Strong Motion Network of Colombia (RNAC) and the National Seismological Network of Colombia (RNSC). Martinez and Chica (1996) [6] proposed equations for the East-West and North-South components of acceleration records for the Andean region in Colombia. Ojeda and Martinez (1997) [7] developed two different empirical models for the attenuation of acceleration in the horizontal components considering the continental faults system and the subduction zone as tectonics regions ruled by different seismological behaviors. In 2000, Gallego [8] estimated the peak ground acceleration based on seismological models of radiated spectra; this analysis was carried out using two representative tectonics settings of Colombia. The most recent GMPE developed for Colombia was done by Bernal and Cordona in 2015 [9], and it is based on the integral, composite and stochastic approaches to model strong motions from kinematic sources. Regarding worldwide attenuation models applicable to Colombia, Bermudez, et al. (2011) [10] statically tested the residuals between response spectra calculated from the RNAC accelerograph database and those estimated using some well-known attenuation models. Results of this analyses suggest that Campbell (1997) [11], Youngs, et al. (1995) [12] and Garcia, et al. (2005) [13] were the models which predicted efficiently the RNAC acceleration values for different tectonics settings such as crustal, interface and intraslab (Benioff) subduction earthquakes, respectively.

In this study, we used data from RNAC database of events associated to the subduction process of the Nazca Plate on the West of Colombia. The events moment magnitude ranged between 4.9 and 7.1, with hypocenters located between 71 and 230 km, recorded at stations with hypocentral distance between 110 and 500 km, located at rock or soil sites (Figure 1b). The quality of every record was tested based on its signal-to-noise ratio, signal continuity and distortion. For the selected records, the RotD50 [14] spectral acceleration values were computed using a damping ratio of 5%, and a GMPE was constructed from the empirical data.

GMPE Sub Colombia versus the BC Hydro model
A database of 249 accelerograms pairs from 19 deep subduction earthquakes recorded between 1995 and 2013 was gathered from 89 stations of the RNAC. This set was used in the development of the attenuation law for deep subduction earthquakes in Colombia. In the database, 163 records were recorded at rock sites. Figure 1a shows the epicentral location of the selected events, along with the RNAC stations location. The epicenters of the events are contained in the Colombian departments of Valle del Cauca, Nariño, Cauca, Chocó, Caldas and Quindío. As a first approach to confirm the necessity of a new GMPE for Colombia, the BC Hydro model [15] was implemented to estimate its residuals with respect to the Colombian empirical dataset. The BC Hydro model is a set of attenuation equations developed as a part of the probabilistic seismic hazard analysis (PSHA) updating of the hydroelectric company BC Hydro at its dams in Canada. It is considered a global subduction models because it was developed based on a data set of 9946 ground motion
record pairs from 292 worldwide subduction zone earthquakes such as Japan, South and Central America, and Mexico among others. Around 6,389 records of BC Hydro’s database are from intraslab events with a 5.0 to 7.9 Mw span.

Figure 1. (a) Epicenters location of selected deep subduction earthquakes in Colombia (circles) and RNAC stations location (red triangles). (b) Span of the dataset: hypocentral distance versus moment magnitude, with soil-type identification.

Figure 2a compares the empirical pseudo-acceleration-distance pairs, for Colombian subduction events with different magnitude, with the BC Hydro Model at the median level. Predictions for two different values of $V_{s30}$ are shown, one representing rock site conditions ($V_{s30} = 1,000$ m/s), and the other soil site conditions ($V_{s30} = 300$ m/s). Figure 2b shows the total residual between the BC Hydro model pseudo accelerations estimations and the empirical data from the RNAC records. The apparent trend of the residuals with magnitude, distance and depth, suggested that a regionalization of the global model was required.

In order to use an independent orientation, the RNAC pseudo-acceleration values used to construct a new GMPE for Colombia correspond to the RotD50 spectrum for each pair of horizontal records. Based on the BC Hydro intraslab model, Equation 1 is proposed to estimate the RotD50 response spectra at a site in Colombia for an intraslab events. Input parameters of the model are: moment magnitude (Mw), hypocentral distance (Rhyp), hypocentral depth (Hypod), soil-flag site conditions (0 for rock; 1 for soil) and sites position with respect to the volcanic arc (0 for forearc; 1 for backarc) represented by the FBA flag.

$$
\ln(S_{\text{RotD50}}) = C_1 + C_2(M - 7.8) + C_3(10 - M)^2 + (C_4 + C_5(M - 7.8))(\ln(R_{\text{Hyp}} + 10e^{0.4(M-6)}) + C_6 \text{Soil-Flag} + C_7 R_{\text{Hyp}} + C_8 \text{Hypod} + C_9 FBA
$$

(1)

Coefficients $C_1, C_2… C_9$ on Equation 1, were estimated following the algorithm described in [16], which includes random effects. Figure 3a compares the empirical pseudo-acceleration-distance pairs, for Colombian subduction events with different magnitude, with the GMPE Sub Colombia model at the median level, for two different site conditions, one representing rock site conditions and the other soil site conditions. Figure 2b shows the total residual between the GMPE
Sub Colombia model pseudo accelerations estimations and the empirical data from the RNAC records.

Figure 2. (a) Comparison of the BC Hydro Model prediction with the empirical data of the deep subduction earthquakes in Colombia (b) Residuals vs magnitude moment Mw, hypocentral distance (Rhypo) and hypocentral depth, for periods 0.02, 0.2 and 2 s at rock (black circles) and soil (red diamond) sites.

Summary

Results of a new ground motion prediction (GMPE) equation for deep subduction earthquakes in Colombia is presented. The Sub Colombia GMPE and the BC Hydro predictions, tend to overestimate pseudo-acceleration values for magnitudes greater than 6.5. However, GMPE Sub Colombia residuals are smaller and centered around zero for the smaller magnitude sets. While the BC Hydro model shows a uniform offset in the residuals for all hypocentral distances, the Sub Colombia GMPE residuals are smaller and tend to be centered around zero. The residuals versus hypocenter depth show a similar behavior as before, although a minor trend is apparent for both, the BC Hydro and the Sub Colombia models.
Figure 3. (a) Comparison of the GMPE Sub Colombia Model prediction with the empirical data of the deep subduction earthquakes in Colombia (b) Residuals vs magnitude moment Mw, hypocentral distance (Rhypo) y hypocentral depth, for periods 0.02, 0.2 and 2 s at rock (black circles) and soil (red diamond) sites.

References


