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A proposal for updating the Response Spectrum of San Jose de Cucuta, Colombia

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Abstract. An analysis of seismic signals captured in three stations of the network of accelerographs of the Colombian Geological Service (SGC, by its acronym in Spanish) was developed for the city of San Jose de Cucuta, Colombia. Earthquake Equivalent, Response Analysis (EERA) and DEGTRA4 software were used for analysis, processing and calculation of signal response spectra during the characterization and propagation modelling of the signal by profiles. For the accelerograms family, a normalization factor computed with respect to the Peak Ground Acceleration (PGA) was obtained by superposition against the typical design spectrum of the Colombian earthquake resistant code (NSR10). It was found that there is a band of frequencies above the maximum acceleration zone of the design spectrum of the current standard. This suggests a revision of the seismic threat of the city of Cucuta and the urgent need to develop the seismic microzoning, which would allow a substantial reduction of the seismic risk.

1. Introduction

In 1875 San Jose de Cucuta (in this work, Cucuta city) was destroyed by a strong earthquake and since then has endured successive periods of seismic crisis. This event killed almost 400 people and is considered as one of the most powerful in Colombia's seismic history. It is of paramount importance to study the seismic threat of Cucuta city because of its history and the high probability that a new crisis can come from the activity of the nearby field sources fault lines that surround the city. Cucuta city and its Metropolitan Area have a population around one million inhabitants and is the main border crossing between Colombia and Venezuela [1]. High hazard and high exposure are naturally combined with the high vulnerability of buildings to produce a high seismic risk. Then, to improve knowledge about seismic risk is necessary to study seismic hazard. To obtain information of the local seismic hazard the response spectra are very useful. They can be used by the engineers to determine the frequencies range that could demand a structural system during the occurrence of a random or deterministic load. The displacement, velocity or acceleration values of an oscillatory system subjected to the action of an external load are analytically assessable if the function that represents the load is a mathematical function [2] for any possible system of a degree of freedom [3]. If

the external load is random (such as an earthquake) the displacements must be computed using numerical techniques. Once response spectra are obtained, digitized signals consisting of a pair of values (time, acceleration) are available. The solution to the problem of dynamic equilibrium of an oscillator is given in terms of a homogeneous solution. The ground movement imposes a displacement to the oscillator mass and an inertial force is generated because of the system stiffness. Such force is continuously modified due to the system damping. Response spectra obtained from real earthquakes are highly irregular and their shapes reflect details of the specific frequency contents and phasing [4]. The concept of response spectrum developed by Beniof (1934), Biot (1941) and Housner (1952) lead to a better evaluation of the (random) seismic response on the simple oscillator. Combination of multiple response spectra lead to the construction of the so-called "elastic spectra" which are commonly used in the Resilient Earthquake Construction Standards and are valid for a given structural damping value (critical fraction) and a certain soil profile. In a typical elastic spectrum, the acceleration level for short periods is determined by the seismic zone while for long periods it is determined by the soil profile. Its construction is usually derived from the effective amplitudes of ground movement and pseudo values [5] such as: a) maximum acceleration, velocity and terrain displacement; b) period of the structural system; c) maximum displacement of the mass relative to the base; d) maximum pseudo velocity and maximum pseudo acceleration. In this paper, analysis and conclusions related to response spectra obtained for three specific sites of Cucuta city are presented. Their dynamic characteristics have been determined from widely accepted empirical correlations in modern engineering.

2. Materials and methods.

2.1. Input information for the model
The information of seismic signals was captured using three accelerograph stations located in three different points of Cucuta city: Profile 1 (CUCC1), profile 2 (CUCC2) and profile 3 (CUCC3). Profiles 1 and 3 correspond to a deposit of rock (weathered arcillolite) of Oligocene tertiary age with a power or depth of 30 meters. Profile 2 corresponds to a very dense soil or soft rock with an approximate depth of 180 meters located on the limnological line of the Pamplonita River, old quaternary. Shear wave velocity varies from 360 m/s to 760 m/s for Profile 2 and from 180 m/s to 360 m/s for Profiles 1 and 3. EERA program was used to determine the dynamic parameters of each profile. DEGTRA4 program was used to determine the response spectra for each profile using the signal recorded in the respective accelerographs.

2.2. Determination of the response spectrum
The general solution of the mathematical system of a simple oscillator in an elastic state can be expressed as two parts: that associated to a homogeneous response, $u(t)_h$ plus a complementary part, $u(t)_c$. The external load is considered as an effective inertial load, so the solution corresponds to that of a homogeneous equation of the form established in equation [2]

$$u(t)' = e^{-\beta t'} \int p(\tau) \sin \omega_d t' d\tau \qquad (1)$$

Where $p(\tau)d\tau$ represents an impulse force that acquires the mass of the system for a succession of impulses. $\omega_d = \omega(1 - \xi^2)^{1/2}$ is the damped frequency that will depend on the damping with respect to the critical, ξ; $\beta = \xi\omega$; Equation (1) can be written as:

$$u(t') = -\left(\frac{1}{\omega_d}\right)\int e^{-\xi\omega(t-\tau)} \ddot{u}_g(\tau)\left[\sin \omega_d t \cos \omega_d \tau - \cos \omega_d t \sin \omega_d \tau\right]d\tau \qquad (2)$$

Once the seismic signal is digitized, pairs of values $\left[\ddot{u}_{gi}, \tau_i \right]$ are obteined. Suchs values will conform the basis of the numerical integration of the equation, that is, the acceleration that is a random value and the time that is a deterministic value. Let $t' = t - \tau$ a convolution condition that allows to express the equation (2) as equation (3):

$$S_d = \left| \frac{1}{\omega_d} \int_0^t e^{-\xi\omega(t-\tau)} \ddot{u}_g(\tau) \sin \ddot{\omega}_d(t-\tau)d\tau \right|_{max} \qquad (3)$$

Where S_d is the spectral displacement. By deriving the equation (3) the pseudo-spectral velocity, S_v is obtained:

$$S_v = \left| \int_0^t e^{-\xi\omega(t-\tau)} \ddot{u}_g(\tau) \cos \omega_d(t-\tau)d\tau + \frac{\xi}{(1-\xi^2)^{1/2}} \int_0^t e^{-\xi\omega(t-\tau)} \ddot{u}_g(\tau) \sin \ddot{\omega}_d(t-\tau)d\tau \right|_{max} \qquad (4)$$

By deriving equation (4) the spectral acceleration, S_a is obtained:

$$S_a = \left| \omega(1-2\xi^2/(1-\xi^2)^{1/2} \int_0^t e^{-\xi\omega(t-\tau)} \ddot{u}_g(\tau) \sin \omega_d(t-\tau)d\tau + 2\xi\omega_d \int_0^t e^{-\xi\omega(t-\tau)} \ddot{u}_g(\tau) \cos \ddot{\omega}_d(t-\tau)d\tau \right|_{max} \qquad (5)$$

The above results can be summarized as follows, equation (6):

$$S_d = \left| \frac{1}{\omega_d} \int_0^t e^{-\xi\omega(t-\tau)} \ddot{u}_g(\tau) \sin \ddot{\omega}_d(t-\tau)d\tau \right|_{max}$$

$$S_v \approx \left| \int_0^t e^{-\xi\omega(t-\tau)} \ddot{u}_g(\tau) \cos\omega_d(t-\tau)d\tau \right|_{max} \qquad S_a = \left| \omega_d \int_0^t e^{-\xi\omega(t-\tau)} \ddot{u}_g(\tau) \sin \ddot{\omega}_d(t-\tau)d\tau \right|_{max} \qquad (6)$$

Summarizing:

$$S_v \approx \omega S_d$$
$$S_a = \omega^2 S_d = \omega S_v$$

The record of earthquakes constitutes, unequivocally, the most important tool in seismic engineering to study the energy released from a seismogenic source and its effects on civil structures [6, 7, 8]. Equations (6) allow to relate the earthquakes records with the structural features and with the soil deposits properties. Such equations are useful to compute the maximum response values in the oscillators (structures) produced by the land movements which are in turn caused by the propagation of seismic waves in the soil [9,10].

3. Results and Discussion

According to the Colombian earthquake resistant code (NSR10) the local effects of seismic response must be evaluated based on the soil profiles. To do so, NSR10 states some procedures and parameters to use. In this work, a comparison between maximum values obtained from NSR10 and those resultant from the application of the procedure described in the precedent section has been made. Figures 1, 2 and 3 show the result obtained for the normalization factor relative to Peak Ground Acceleration (PGA) for stations CCUC1, CCUC2 and CCUC3 normalized response spectra. The black band in the figures corresponds to the design spectrum of the NSR10.
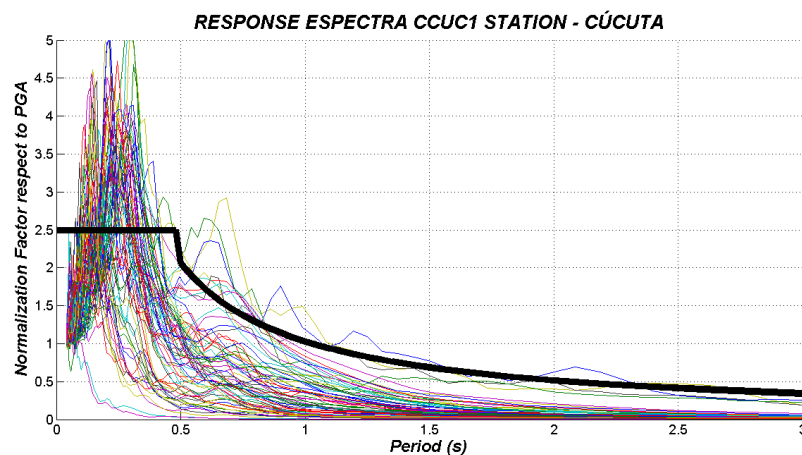
Figure 1. Normalized response spectra from CCUC1 data.
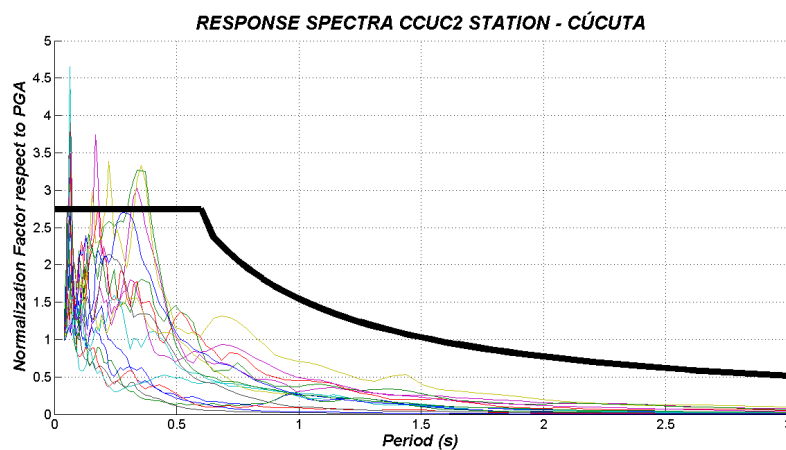
Figure 2. Normalized response spectra from CCUC2 data.
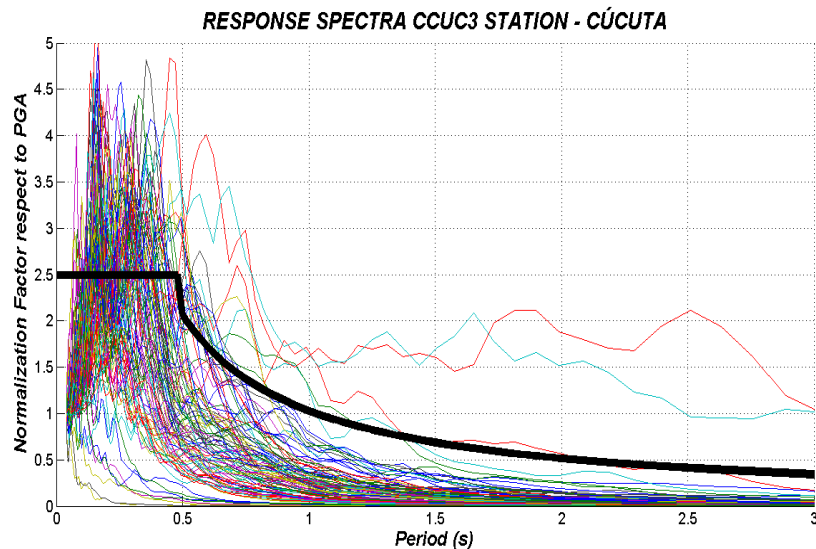
Figure 3. Normalized response spectra from CCUC3 data.

4. Conclusions

In the three studied sites, a high concentration of frequencies within a range from 5 to 6 Hz (periods from 0.17 to 0.20 s) is observed in figures 1, 2 and 3. Indeed, this range delimits the frequency characteristics of each earthquake family. The dominant frequency content in the signal can be linked to a frequencies band delimited between 6 and 7 Hz. This range is probably highly influenced by the soil profile characteristics, i.e. is mainly defined by the geomechanical characteristics and geometry of rigid soil deposits. The response spectra show an important amplification when period is low ($0.1 < T < 1.0$ s). This suggests that for buildings with less than five floors could be in high risk if an earthquake with magnitudes between 6.0 and 7.0 occurs. When comparing the family of response spectra for the three soil deposits against the profile type of the elastic design spectrum of the NSR10 a band of spectral accelerations is clearly shown that are above the range of short periods of the spectrum. This suggests that a rigorous review should be made of the site effects that would be occurring in the city's soil profiles. Hence the imperative need to conduct a seismic microzoning study.

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