FEASIBILITY STUDY OF VS20-BASED DESIGN SPECTRA FOR THE URBAN AREA OF MANAGUA, NICARAGUA

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ABSTRACT

I proposed design spectra considering the non-linear site response base on the amplification factor of 40 velocity profiles located in the urban zone of Managua, Nicaragua. The method applied the multichannel surface analysis (MASW) of 22 different places and 18 different reference points provided by Rojas et al. (2016), Escorcia et al. (2013), and Facciolli et al. (1973); to provide the shear wave velocity profile and propose a soil classification map based on the Vs-20 analysis of the study area. The non-linear response spectra were developed from the backbone curve using the linear equivalent and hyperbolic model fitted with the dynamic deformation laboratory test data provided by Facciolli (1973). The soil amplification factors and design response spectra were defined using the soil classification map and the non-linear response spectra.

The results showed that the zones with the lower shear velocity have larger soil amplification factors and were located in the northern zone on the coast of Managua Lake. Second, the calculation of the reference points using Vs-20 had the best fitted distribution made by geology and land use constraints. Finally, the developed design spectra for this study proposed a soil classification that included a soft soil design spectra and moderate soft soil with three differences range limits in the spectral acceleration branch.

Keywords: Design Response Spectra, Amplification Factor, MASW method, Seismic Micro-zonation.

1. INTRODUCTION

Managua, the capital of Nicaragua, is the city with the highest seismic activities in the country due to the location on the Pacific coast that is mainly affected by the subduction zone. The Pacific coast of Nicaragua is part of the ring of fire and; this zone is characterized by the subduction of the Coco plate beneath the Caribbean plate, and the principal consequences of this are the volcanic activity and the historical large earthquakes in shallow and intermedia depths. In addition, the city is affected by the shallow inland earthquakes product of the effect of the geological settings, geological faults and the soft soil conditions established by an alluvial fan located in the city.

The national seismic code of Nicaragua (RNC-07) presents a dynamic analysis using the linear elastic system, unlike the inelastic analysis. Therefore, knowing the inelastic soil conditions and predicting the site response through seismic hazard studies is a very important task. A greater knowledge of soil conditions allows reducing the uncertainty in soil conditions and facilitates the prediction of the probable affectations that the structures may suffer during a seismic event. The purpose of this study is to estimate the amplification factor based on the design response spectra proposed using the shear wave velocity profiles for the urban area of Managua and define a seismic micro-zonation shear wave velocity map.

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2. DATA

In this study, the earthquake records were used to calculate the frequency domain analysis of the soil profile structures. In total 30 records data were selected to satisfy the following criteria: a) recorded at a rock site, b) period range between 0.1 and 1.0 secs, c) cover a wide range of peak acceleration values (0.6 to 1.2 g).

Table 1. Record of Strong Motion data by PEER Catalog.

Country	No.	Year	Mag.
Nicaragua	3	1972	5.00 - 6.24
El Salvador	3	1986 - 2001	7.50 – 7.70
Mexico	8	1985-2010	5.40 - 7.20
Costa Rica	2	1991	7.50
Imperial Valley	3	1940	5.01
Loma Prieta	2	1989	6.93
Coyote Lake	2	1979	5.74
Mammoth Lakes	2	1980	5.69
Parkfield	1	1966	6.19
Chi-Chi, Taiwan	1	1999	7.62
L'Aquila, Italy	1	2009	6.30
Iwate, Japan	1	2008	6.90
New Zealand	1	2011	6.20

The type of earthquakes was selected according to the probability of occurrence and similar tectonics conditions of Nicaragua. In consequence, the strong motion records have been selected in Central America, Mexico and California Area (Table 1). The nonlinear seismic analysis was considered for the design ground motion in base on the hazard map with a return period of 475 years by RNC-07. Therefore, for each soil category and for five levels of expected intensity in rock site (PGA rock > 0.1g, 0.1g > PGA > 0.2 g, 0.2g > PGA > 0.3 g, 0.3g > PGA > 0.4 g, 0.4g > PGA > 0.5g) spectral acceleration factors at the surface were determined for the amplification factor and an intensity of 0.3 g in rock site for Managua.

3. THEORY AND METHODOLOGY

3.1. Frequency domain analysis

The response of the soil spectra to the base rock motion is calculated using the frequency domain analysis. This method uses the ground motions associated with the vertical propagation of shear waves between two layers. The methodology used the development of transfer functions for multi-stratified soils; using N horizontal layers, of which each layer defines the properties in the half space as the bottom layer. The calculation starts with the assumption that the soil only has a vertical propagation of shear velocity and that it originates only a horizontal displacement in Eq. (1).

$$u=u(x,t) \tag{1}$$

The complex shear modulus formula was defined in terms of the critical damping ratio instead of the viscosity; therefore, the critical damping ratio assumes the independence of the frequency using the Eq. (2). Finally, Eq. (3) shows the transfer function defined between half-space rock strong motion and the free surface.

$$G^* = G.\left(1-2\xi^2 + j2\xi\sqrt{1-\xi^2}\right) \tag{2}$$

$$A_m = \frac{2e_1(\omega)}{2e_N(\omega)} \tag{3}$$

3.2. Shear wave velocity

The shear wave velocity calculated for this study used a database of 40 reference points with 6 SPT, 12 reference points collected from other researches and 22 using MASW method. The MASW analysis can obtain a shear velocity model defining the variation of near-surface soil layers around the linear arrangement. In order to complement the information available for the city of Managua, the shear velocity profile of the data processing using the MASW analysis is calculated with the following procedure:

i. Surface Data wave measurement: the waves will be registered with a roadside linear arrangement. The arrangement consists of eight vertical seismometers of 2.0 Hz, spaced each other with 2 m, these geophones measured the surface waves generated using an artificial resource located at 16 m. The total length of the arrangement was 80 m.
ii. Dispersion Curve analysis: using the MATLAB code was define the dispersion curve in terms of phase velocity (c) and frequency (ω) using the sum of all the phase-shifted traces (N).
iii. Inversion Model: This analysis used the iteration process to estimate the theoretic soil profile collected by tested synthetic data. I apply the dispersion curve to define the theoretical model using the program Dinver/Geopsy.

4. RESULTS AND DISCUSSION

4.1. Hybrid vs20 mapping strategy

The strategy to develop a soil classification map used the Vs-20 and common indicators variables to define the micro-zonation analysis for the study area. The calculation of the reference points using Vs-20 had depth with the best fitted distribution made using the indicators the parameters present in the constraint map. I consider two different approaches depending on the common observational constraints: the geology and land use correlation into a single map of Vs-20. The combination of geology and land-use take into account to generate a micro-zonation that considers the main characteristics of these resources.

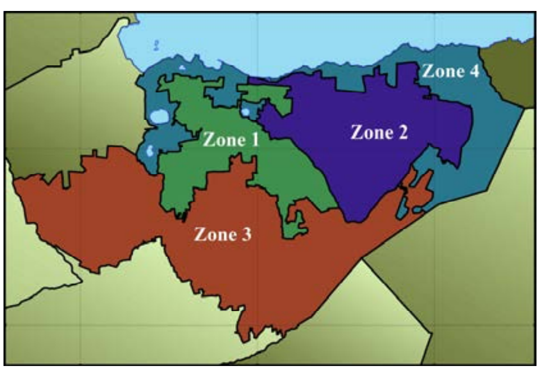

Figure 1. Micro-zonation map of the urban area in Managua using Vs-20.

First of all, the categorical predictor of geology proposed is an extract compiled from the geological map collected by Nicaraguan Institute of territorial studies (INETER) and Czech development agency (CzechAid) (INETER, 2002); this map summarizes the general geology of Managua and surrounding areas. This map shows the geological units generated in this proposal to calculate the zones of influence for the micro-zonation of the urban area of Managua. The main geological units of Managua are divided in: Artificial Fill, Holocene, Pleistocene, Plio-Miocene and Tertiary.

Second, I calculate a restructured land use base in the generalized map of Managua proposed by INETER in 2010, which is divided into urban and rural areas. For this study, the land use map was complemented the urban zones to make a subdivision using the urban model show in the topographic map of the city and present a classification with a with direct influence on the soil profiles. The new areas of influence were divided in: house class A, B and C, commercial zones, education centers, residential and industrial zones.

Finally, the trend estimate to calculation process is used to define the interpolation of the soil classification map for the study area. From this relationship of terms between the predictive category of Geology and Land use, the study area was divided into four different zones which are shown in Figure 1.

Zone 1 represents the residential houses located in the northwest area of the downtown, including type A, B, and C houses; this part have a dense deposits of alluvial fan originating from las Sierras formation. Zone 2, which covers the education centers, and commercial area that is located northeast, is composed mainly of the dense deposits of alluvial fans. Zone 3 is composed of ashes, alluvium fans and volcanic rocks from Masaya volcano; this region represents the marginal area in the south of the city that includes the forest, open space and agricultural areas. Zone 4 is represented by the coastal area and industrial zone in the east of the downtown, mainly composed of artificial fill and alluvium fans.

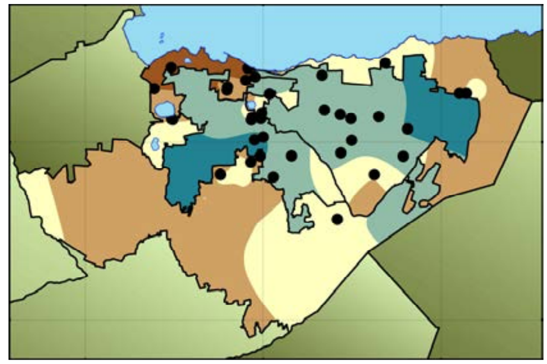

Figure 2. Soil classification map based on Vs-20 analysis of Managua.

4.2. Non-linear behavior of the Soil Profile

The performance of the hyperbolic model and the equivalent linear model was calculated in the profile corresponds to the National Autonomous University of Nicaragua station in the south part of the study area. The equivalent linear analysis was obtained from theoretical dynamic curves proposed by Electric Power Research Institute (EPRI, 1993) and the non-linear behavior fitted with the hyperbolic model using the study elaborated by Faccioli, Santoyo V., and León T. (1973). The shear modulus and damping values derived from the data collected by Faccioli (1973) at the ESSO station, located about 10 meters below the ground with a confining pressure of 1,156 kg / cm².

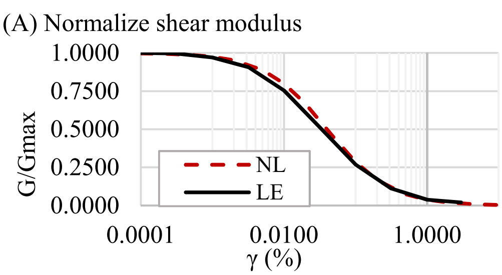

Figure 3. Comparison between normalized shear modulus fitting using the data test by Facciolli (1973).

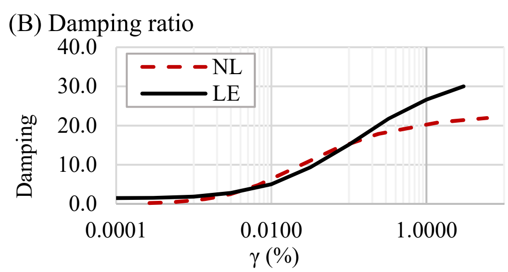

Figure 4. Comparison between damping ratio reduction curve fitting using the data test by Facciolli (1973).

The use of the hyperbolic model overestimates the spectral acceleration in the short ranges of shear strain (0.002 to 0.2) compare with to the linear model. On the contrary, the damping ratio in the long strain ranges with the hyperbolic model has a 5% of underestimation compared with the equivalent linear analysis. Finally, it can be seen that the line model presents a curve with maximum stress of 23 kPa.

The surface response spectra using the strong motion database (Table 1), with 0.1 and 0.3 PGA was defining for the linear and non-linear analyses. For 0.1 PGA a smaller difference can be appreciated (3.33%), the maximum acceleration is found in 0.1 sec. Contrarily, with 0.3 PGA the values in the acceleration increased, but the inelastic method begins to reduce its acceleration proportionally, the difference between the two models was 19.81%.

4.3. Design response spectra analysis

In this chapter, I proposed an improvement in the design response spectra for the different soil conditions based on the analysis of soil profiles generated for this study, which are defined with the characteristics of the seismic ground response. I used the database of soil profiles calculated in the urban area of Managua and database collected (Table 1). Emphasizing in the proposed model using the non-linear hyperbolic method, I have taken into account the amplification produced by the thickness of soil deposits, the impedance ratio affected in soil behavior and the degradation curve that verifies the variation of the normalized shear modulus reduction of the soil profile in Managua.

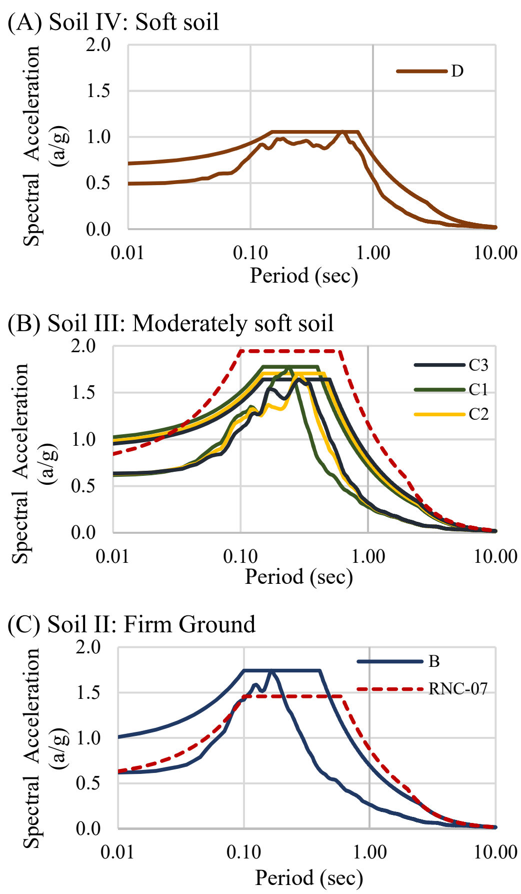

Figure 5. Comparison between the proposed design response spectrum and RNC-07.

Figure 5 shows the maximum acceleration proposed in the ground surface of all the influence zones in the seismic classification map; as the reference, the elastic response spectra proposed by RNC-07 was calculated except the soft soil (shear velocities between 180 to 270 m/s. In these values, it can be seen the average response spectra have a direct agreement with the reference spectrum.

First, soft soil (shear velocity between 180 to 270 m / s) is shown in Figure 5(A); it did not have its amplification values in the seismic code of Nicaragua. The maximum value of the response spectra had 1.06 g, the lower load capacity in the micro-zonation areas; this is due to the shear strain shown by said profiles that can cause the soil profile to exceed the limits values of shear stress presented. This soil profile is more likely to present liquefaction effects, due to the presence of water table at surface level, the contact with the Managua coast and the high clay content shown throughout the area.

Second, Figure 5(B) show the design response spectra proposed for moderately soft soil conditions, which had overestimation compared with the RNC-07, being an adequate safety factor, but it is necessary to make an adjustment in the limited periods that will be proposed in this document.

Finally, Figure 5(C) shows the spectrum for firm ground, and the maximum value of the response spectrum had underestimation of 19%. Therefore, the spectral amplification parameters were redefined to adjust to the maximum acceleration in the design spectrum.

The calculated values for high shear velocity show the maximum variability from the curve proposed by RNC-07. On the contrary, the proposal of the acceleration response spectra in the moderately soft soil (Soil C1, C2, C3) has small values of the national seismic code. Therefore, the RNC-07 has a good behavior with a safety factor of 9% with a reasonable amplitude of periods for the spectral acceleration branch. Finally, Figure 5(C) shows the proposal for soft soil; since this type of soil is not evaluated in the RNC-07, this model will be an initial proposal spectrum, with an acceleration of 1.10 g, with a period range of the spectral acceleration branch between 0.15 and 0.75 sec.

5. CONCLUSIONS

The feasibility study of vs20-based design spectra was conducted for the urban area of Managua using the soil profile of the downtown calculated with the MASW method to calculate the non-linear analysis to estimate the response spectra and the soil classification map. The following conclusions were made:

i. The calculation of the reference points using Vs-20 had depth with the best fitted distribution made by geology and land use constraints.
ii. The areas with the highest velocities are located in the east part of the city with values greater than 540 m/s. Instead, the lowest velocities are found in the north zone, near the coast of Managua lake, with values lower than 200 m/s.
iii. The moderate soft soil was included as Subdivision in the classification of the response spectra (C1, C2, C3), which had similar spectral acceleration conditions, but with a different range of the limits in the spectral acceleration branch.
iv. The design spectrum Proposal for soft soil had a low value of spectral acceleration with a wide range of the limits in the spectral acceleration branch.

6. RECOMMENDATION

Although the research has tried to study the effect of the site in the urban area of Managua with the available data, these results should be taken as an initial proposal, therefore an extension of the local site effects at site response should be done, using data from earthquakes with different conditions and newly proposed reference sites. According to the above reasons, I recommend the following suggestions:

i. To confirm site amplification proposed in this paper, it is necessary to compare the soil profiles with reference points applying calculations using other microtremor methods and drilling to check the accuracy of the soil profiles.
ii. To find a wide range of the amplification factor is recommended to complement with high frequency strong motion data (frequencies greater than 1 sec).
iii. Add points in an area with higher elevation in such a way that you can make a comparative analysis with a topographic slope map.

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