EFFECT OF SURFACE GEOLOGY (CONSIDERING NONLINEARITY OF SUBSOIL) ON GROUND MOTION IN THE URBAN AREA OF MANAGUA, NICARAGUA

Delvin Martinez* **Supervisor: Hiroshi ARAI****
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ABSTRACT

The purpose of this study is to evaluate the site response on ground motion in the urban area of Managua, Nicaragua, considering nonlinear behavior of the subsoil, using the program EERA, which is based on the equivalent linear soil model. The site response models were constructed using shear wave profiles, which were obtained by applying a geophysics method (MASW) in the target area, geotechnical and geological data available at the sites. The numerical simulation programs used in this study can be downloaded from http://gees.usc.edu/GEES/ . In this study, seven site response analyses were carried out using the input ground acceleration recorded during the 1972 Managua Earthquake. Based on the EERA analyses results, the ground motion in the target area is strongly affected by the first ten meters of soil which are mainly composed of silty sand, classified as "moderate soft soil", with shear wave velocity between 180 m/s and 360 m/s. Comparing the response acceleration spectrum obtained at each site with the design acceleration spectrum, provided by the Nicaragua Seismic Code, the design spectrum for the Managua area can be considered as overestimated. In addition, the liquefaction potential was evaluated in two cases with different water levels. In both cases, the liquefaction is supposed to occur between the depths 2.1 and 5.6 meters, corresponding to the layers composed mainly for silty sand. The severity of the liquefaction expected is classified as moderate to minor liquefaction, according to the liquefaction potential index estimated.

Keywords: Ground response, bedrock motion, rock outcropping motion, liquefaction potential, liquefaction potential index.

1. INTRODUCTION

The distribution of earthquake damage is strongly influenced by the response of soils under cyclic loading. This response is controlled in large part by the mechanical properties of the soil. The evaluation of ground response is one of the most important and most commonly encountered problems in geotechnical earthquake engineering. Ground response analyses are used to predict ground surface motions for the development of design response spectra, to evaluate dynamic stresses and strain for the evaluation of liquefaction hazards, and to determine the earthquake-induced forces that can lead to the instability of earth and earth-retaining structures.

In this study, the computer program EERA (Bardet et al., 2000) is applied with the objective to evaluate the effect of surface geology (considering nonlinearity of subsoil) on ground motion in the urban area of Managua, Nicaragua. Several soil profiles (shear wave velocity and geotechnical profiles) obtained around the urban area of the city will is used.

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* Geoscientific Research Center, Managua City, Nicaragua
** National Institute for Land and Infrastructure Management, Tsukuba, Ibaraki, Japan.

In addition, the liquefaction potential is estimated by means of the analysis of shear wave velocities and the results obtained from ground response analysis performed at each site. The evaluation of the liquefaction potential was performed in two cases with different water levels.

2. DATA

In this study, the input ground motion used is the record time history acceleration recorded during the 1972 Managua earthquake (Figure 1), in the ESSO refinery seismic station (indicated by red star in Figure 2), deconvolved to "bedrock". The instrument in this site had a nominal range of 0.5g (Engineering Report "1972 Managua Earthquake", 1975). The maximum acceleration is 0.218g at 6.420 seconds. It was localized beneath the center of Managua, the capital of Nicaragua. The materials in this site are predominately composed of sandstone, tuff, marl and shale (INETER, 2003) and density on the surface layer is 1.6 t/m^3 (Faciolli et al., 1973)

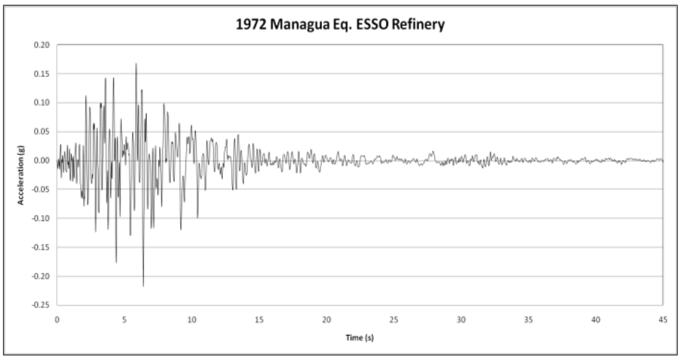

Figure 1. Acceleration time record, EW component, 1975 Managua Earthquake.

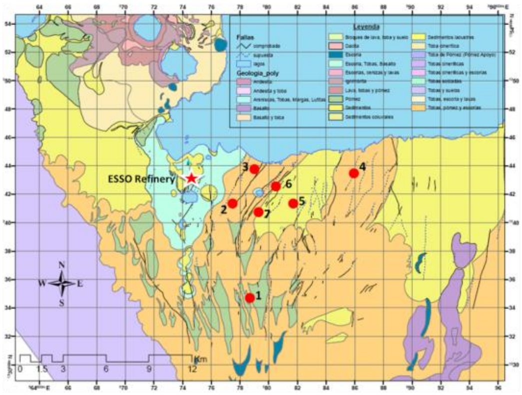

Figure 2. Site simulated into geological map of the Managua city (INETER, 2003)

Seven sites (red points in Figure 2), distributed around the urban area of Managua city, were simulated. The geological and geotechnical conditions (including dynamic properties of the soil at each layer) were taken into account. This information was obtained from several studies performed in the target area.

3. THEORY AND METHODOLOGY

3.1. Shear wave velocity profiles

The shear wave velocity profiles, for each site considered, were obtained by means of seismic surveys performed with the geophysics method, called Multichannel Analysis of Surface Waves, MASW (Park et al., 1999). The field work was developed following the procedures established by Park et al., (1999), using the conventionally arrays. This arrays permit to check in situ (to each instant) the quality of each record and solve any problems that can be presented.

3.2. Ground response analysis

To perform the ground response analysis, the method applied was the "Equivalent Linear Method" compiled by the computer program EERA. The software EERA, is a modern implementation of the well-known concepts of equivalent-linear earthquake site response analysis, which was previously implemented in original SHAKE and the subsequent version SHAKE91 (Schnabel et al., 1972; and Idriss and Sun, 1992), takes full advantages of the dynamic array dimensioning and matrix operations in FORTRAN 90, input and output are fully integrated with the spreadsheet program Excel. That means that all the characteristic and numerical accuracy of the Excel are taken advantage, mainly on inputting data like the acceleration files. Even the small values can be taken into account as far as the lower limit of the Excel program. On the other hand, in the case of the strain values (that are very sensitive), it can be taken into account that the full spectrum of the numerical accuracy is given by Excel, which have significant and important influence on the final ground response.

3.3. Evaluation of liquefaction potential

From the results of ground response analysis, the peak ground acceleration and shear wave velocities are used to estimate the liquefaction potential, following the simple procedure by Seed and Idris (1971). The Safety against Liquefaction (FL) value is the criterion to apply, considering the simplicity of this method when the information from laboratory tests is limited.

- FL>1, liquefaction will not occur
- FL≤1, liquefaction is supposed to occur under specified earthquake conditions

The liquefaction phenomenon is very close related with the depth to the water level. In this study, the depth to the water level was assumed, through two possible scenarios that could be occur. Firstly, was considered the worse scenario that could be presented, the water level reaches to the surface and the soil layers are in saturated conditions. Secondly, the water level was assumed to a depth of 5 meters, considering that all the layers above to that depth are in dry conditions and the below layers in saturated conditions. In both case the liquefaction potential was evaluated.

4. RESULTS AND DISCUSSION

4.1. Shear wave velocity

Based on the criterion established by the Nicaraguan Seismic Code (bedrock, any layer with Vs>750 m/s), the shear wave velocity profiles determined, show that the bedrock on the sites simulated is found 15 meters in depth. Table 1 shows the depth at which the bedrock was found at each site and its geotechnical description. The depth to the bedrock varies between 15 meters (Baseball Stadium site) and 44 meters (CIGEO seismic station site).

Table 1. Depth to the bedrock and its shear wave velocity respective for each site to simulate

Site	Depth (m)	Vs (m/s)	Description
CIGEO seismic station	44	780	Poorly graded sand with silty sand, volcanic origin, density 1.5 t/m^3.
Baseball National Stadium	15	750	Moderate dense poorly graded gravel, density 1.85 t/m^3
The Old Cathedral	20	750	Poorly graded gravel with mix with pieces of rock, density 1.90 t/m^3
Cerveceria Nacional site	25	755	Dense poorly graded gravel, density 1.91 t/m^3
Cristo Rey	20	750	Poorly graded gravel, density 1.90 t/m^3
RUCFA	30	900	Poorly graded gravel, density 1.92 t/m^3
UNI-IES	25	750	Poorly graded gravel, density 1.9 t/m^3

According to these results, the depth to the bedrock in Managua urban area is variable, and it is not possible to assume a uniform depth. At each site the bedrock was considered as elastic, with constant shear modulus and critical damping ratio equal to 1% (Kramer, 1996). The shear modulus is constant and depends on the shear wave velocity and density value in the bedrock. Basically, the bedrock in Managua city is composed of poorly graded gravel, with density around 1.9 t/m^3, and shear wave velocity about 780 m/s in average. This material, same as all the soil in Managua city, which is of volcanic origin, locally called “cantera”.

4.2. Shear strain analysis

Typically the shear strains below about 0.001% do not induce significant nonlinear stress-strain behavior in the soil (Kramer, 1996). In this study, the range of the strain analysis considered was between 0.0001% and 1.0% by means of the soil models used. The Table 2 shows the maximum shear strain computed at each site, which values are less than 0.1%, which means that methodology used (Equivalent linear method) is the appropriate to this analysis, and the results obtained at each site are reliable.

Table 2. Maximum shear strain computed at each site

Site	Depth (m)	Maximum shear strain (%)
CIGEO seismic station	3.0	0.056
Baseball National Stadium	8.4	0.028
The Old Cathedral	8.7	0.033
Cerveceria Nacional site	4.7	0.091
Cristo Rey	8.7	0.028
RUCFA	2.5	0.044
UNI-IES	7.0	0.043

The obtained results show, the effect of nonlinearity in the subsoil in the sites simulated can be considered as not strong, which could be related with the magnitude of the input ground motion used (6.2M_W), which is expected cannot produce larges shear strain as was found. The layers that present the bigger shear strain are mainly composed for inorganic silt, silty sand and poorly graded sands, with shear wave velocity between 200 and 400 m/s, which indicate that is not possible to establish a relationship using the properties of the soil, at least in these cases.

4.3. Peak ground parameters

Table 3. Depth to the bedrock and its shear wave velocity respective for each site to simulate

Sites	PGA		T	f_0 (Hz)			Amp		
	(g)	(gal)	(s)	1	2	3	1	2	3
CIGEO	0.516	506.06	0.40	2.4	6	8.8	3.5	3.45	3.39
Baseball Stadium	0.318	311.96	0.16	6.2	15	>25	3.33	2.95	-
Old Cathedral	0.324	317.43	0.18	5.6	14	23.80	3.32	2.73	1.89
Cerveceria Nacional	0.378	370.23	0.20	5.4	-	-	3.76	-	-
Cristo Rey	0.322	315.40	0.19	5.6	13.6	22.4	3.41	2.86	2
RUCFA	0.415	406.83	0.23	5.2	10.6	24.1	3.97	3.74	1.61
UNI-IES	0.403	395.43	0.24	5	11.6	18	3.5	2.93	2.28

Table 3 shows the peak ground acceleration (PGA) at the surface layer, the fundamental period (T), the peak frequencies of resonances (f_0) and the amplification factor for each vibration mode.

The peak ground acceleration values obtained at the top of the surface layer show relatively high values. The obtained fundamental periods which correspond to the first vibration modes at each site, vary between 0.16 and 0.40 seconds that can be related with moderate soft soil (RNC – 07). Three vibration modes were estimated, except in Ceveceria Nacional site, where it was possible to detect only the first vibration mode.

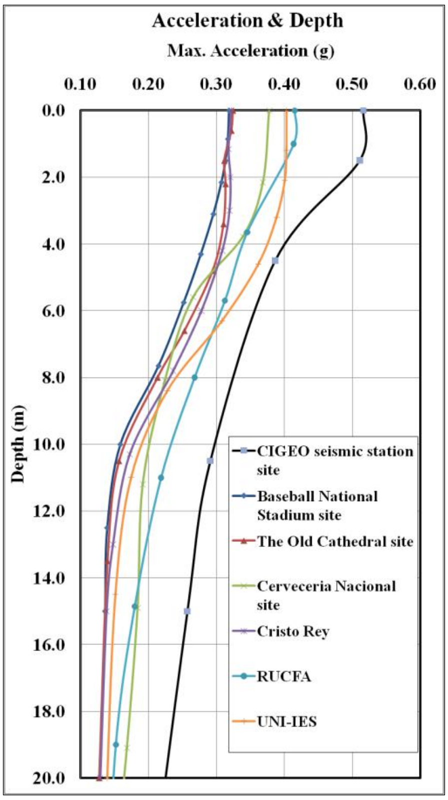

Figure 3. Computed maximum acceleration at the top of each layer within the entire soil column at the sites simulated

The variation of the peak ground acceleration in depth (Figure 3) shows the strong influence of the soils deposited on the first ten meters on the ground at each site, composed mainly of silty sands and silt, which is classified as Soil type III (moderate soft soil) in the Nicaraguan Seismic Code.

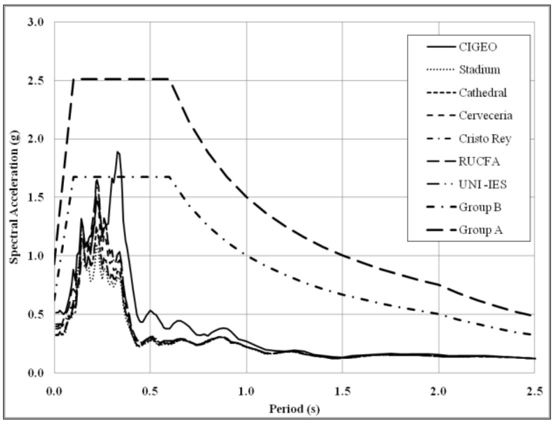

Figure 4. Response acceleration spectrum at each site and design acceleration spectrum for Managua city provided by RNC – 07 for structures of Group A and B, in soil type III.

The response acceleration spectrum obtained at each site compared with the design response acceleration provided by the Nicaraguan Seismic Code (Figure 4) shows that the peak spectral values obtained are below to the design values.

4.4. Liquefaction potential

Two cases were considered (Case 1 and Case 2), considering different depth to the water level (0 and 5 meters). The Figures 5 and 6, show the results obtained at both cases. In general, in both case, the liquefaction is supposed to occur between the depths 2.1 and 5.6 meters, which correspond to the layers composed mainly for silty sand, with shear wave velocity between 170 and 200 m/s. The severity of the liquefaction expected is

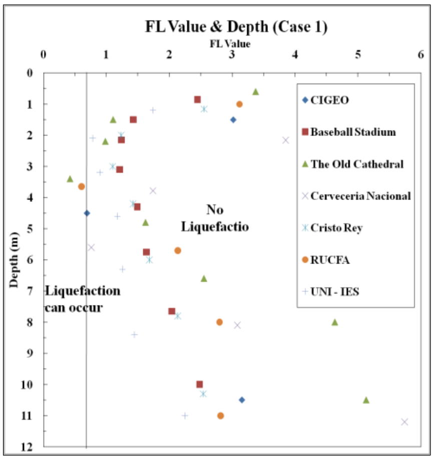

Figure 5. FL value & depth results, Case 1

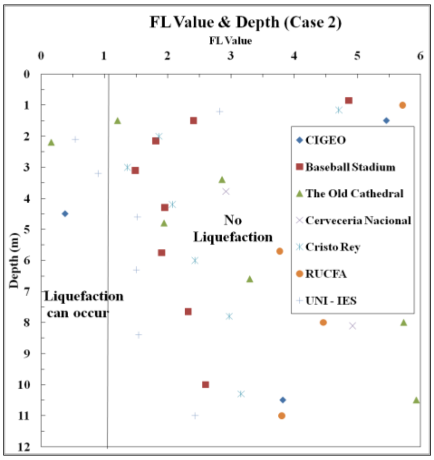

Figure 6. FL value & depth results, Case 2

classified as moderate to minor liquefaction, according to the liquefaction potential index estimated (PL).

5. CONCLUSIONS

The results of the measurements of shear wave velocity which were obtained at each site simulated, show that the depth to the bedrock in Managua urban area is variable and it is impossible to establish a single depth to the entire city. The maximum shear strain computed at each site is less than 0.1%, which means that the obtained results with the equivalent linear method are quite reliable. In general three vibration modes were found and the dominant period in the range from 0.16 seconds to 0.40 seconds, which are related with hard soils and moderate soft soils, with amplification factor values less than 4 times. The variation of the peak ground acceleration in depth shows the strong influence of the soils deposited on the first 10 meters on the ground at each site is mainly composed of silty sands and silt. From the Nicaraguan Seismic Code it is classified as moderate soft soil in the Nicaraguan seismic code. Through the comparison of the response acceleration spectrum obtained at each site and the design response spectrum provided by the Nicaragua Seismic Code was found that for this earthquake the design values are overestimated in the Managua case. The liquefaction is supposed to occur between the depths 2.1 and 5.6 meters, which severity supposed can be classified as moderate to minor liquefaction, according to the liquefaction potential index values estimated.

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REFERENCES

Bardet, J. P., Ichii, K. and Lin, C. H., 2000. EERA: A Computer Program for Equivalent-linear Earthquake site Response Analysis of Layered Soil Deposits, University of Southern California, Department of Civil Engineering, http://geoinfo.usc.edu/gees.

Engineering report on the Managua earthquake of 23 december 1972, 1975. National Academy of sciences, University of Illinois.

Faccioli, E., Santoyo, E. and León J. T., 1973. Microzonation criteria and seismic response studies for the city of Managua. Proceedings of the Conference on the Managua, Nicaragua Earthquake of December 23, 1972, vol. II, San Francisco, C.A. 29-30 Nov. 1973, pp. 271-291.

INETER, Microzonificacion Sismica de Managua

Idriss, I. M. and Sun, J. I. 1992. User's Manual for SHAKE91, Center for Geotechnical Modeling, Department of Civil Engineering, University of California, Davis.

Kramer, S. L., 1996. Geotechnical Earthquake Engineering, Prentice Hall, Upper Saddle River, New Jersey, pp.254 - 280.

Park, C.B., Miller, R.D., and Xia, J., 1999, Multichannel analysis of surface waves: Geophysics, v. 64, n. 3, 800-808.

RNC, 2007. Reglamento Nacional de Construcción de Nicaragua. Ministerio de transporte e infraestructura. Dirección general de normas de construcción y desarrollo urbano.

Schnabel, P. B., Lysmer, J., and Seed, H. B., 1972. SHAKE: A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites, Report No. UCB/EERC-72/12, Earthquake Engineering Research Center, University of California, Berkeley, December, 102p.