Seismic site effects in the city of Mendoza and surroundings (Argentina)

Effets de site sismique dans la ville de Mendoza et les environs (Argentine)

Barchiesi A.M., Mancipe-Herrera C.
Geotechnical Research Section - IMERIS, Faculty of Engineering, National Cuyo University, Mendoza, Argentina.

ABSTRACT: The city of Mendoza and its surroundings constitute an urban nucleus developed in a region of strong seismic activity. Therefore, studies aimed to establishing the local seismic response are needed. The first stage of these studies are given by the compilation of geotechnical information enabling an approximate characterization of the existing alluvial deposits, in terms of their shear wave velocities, soil densities and stiffness and damping degradation curves. On the other hand, assessments on the seismic site effects were made taking into account the seismicity of the area by means of signals representing earthquakes both in near field condition and in far and intermediate distant condition. Both activities have been carried out from the available information that is not completely enough for a definitive study. This paper presents a synthesis of calculations of seismic site effects in different points of the urban area are presented as information basis for the preparation of maps of free field maximum accelerations, surface amplifications and design spectra.

RÉSUMÉ : La ville de Mendoza et ses alentours constituent un noyau urbain développé dans une région de forte activité sismique. Il faut donc des études visant à établir la réponse sismique locale. La première étape de telles études est donnée par la compilation d'informations géotechniques permettant une caractérisation approximative des dépôts alluvions existants, en fonction de leur vitesse des ondes de cisaillement, la densité du sol et des courbes de dégradation de la rigidité et l'amortissement. En revanche, les évaluations sur les effets de site sismique ont été faites au moyen de signaux des tremblements de terre les deux près de conditions sur le terrain et en état proxène, lointain et intermédiaire, en tenant compte de l'activité sismique de la région. Les deux activités ont été menées après les informations disponibles ne sont pas assez complètement pour une étude définitive. Ce document présente une synthèse des calculs des effets de site sismique en différents points de l'agglomération comme base d'information pour la préparation de cartes des accélérations maximales de champ libre, les amplifications de surfaces et les spectres del design.

KEYWORDS: Mendoza, seismic site effects, seismic micro-zonation, near field condition.

1 INTRODUCTION

Mendoza city and its surroundings, in the province of Mendoza, is the fourth city by number of inhabitants of Argentina, with about 850,000 inhabitants. Figures 1 and 2 illustrate the location of the area and its six municipalities: Las Heras, Guaymallén, Maipu, Godoy Cruz, Luján de Cuyo, and Capital (or Mendoza city).

The area has been subjected to various seismic events during its history, the most important of which was on the 20 March 1861 earthquake (estimated Richter magnitude: 7.2) with lX Mercalli intensity. According to Mingorance 2006, the epicenter of this event was located in the La Cal fault zone (though the INPRES placed the epicenter in Barrancas, Maipú, Mendoza).

During the 20th century the area was affected directly by events smaller than the aforementioned ones: 26 January 1985 (M: 5.7) with epicenter in Barrancas (25km to Mendoza city) according to Poder Ejecutivo Nacional 1989.

This paper concerns a synthesis of the research developed to determine approximately the surface seismic loads based on the information available.

One aspect that has received particular attention is given by the seismic site effects corresponding to the amplifications and modifications that suffer the seismic loads when arriving to the surface associated with the geotechnical characteristics of each particular site. A general presentation of the problem can be seen in Barchiesi et al 2010 and Barchiesi 2010. A more detailed presentation can be found in Lanzo & Silvestri 1999.

A preliminary zoning based on the expected response, taking into account the results of maximum acceleration, spectra of pseudo-acceleration and periods of amplification was performed in this study.

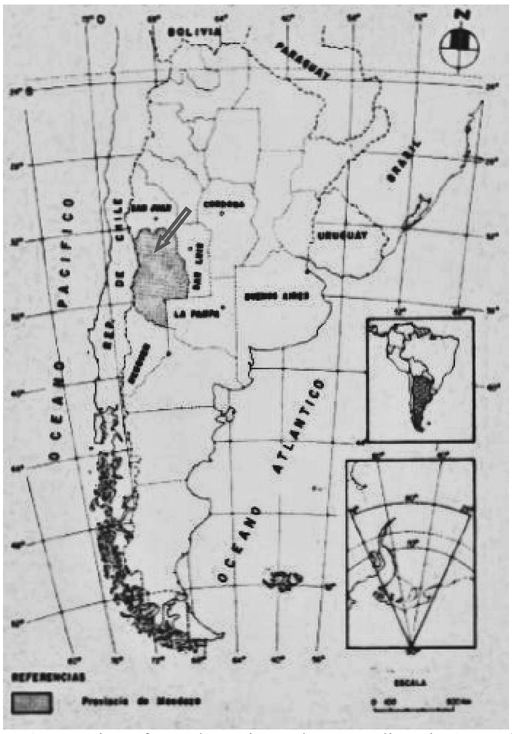

Figure 1: Location of Mendoza city and surroundings in Argentina

Also a study of sensitivity whereas the great uncertainty of geotechnical parameters was taken into account was developed.

The information available is not enough to establish design spectra or zoning for design in engineering.

2 GEOTECHNICAL CHARACTERIZATION

The reference Poder Ejecutivo Nacional 1989 collects the geological information of the study area which is basically of Holocene age.

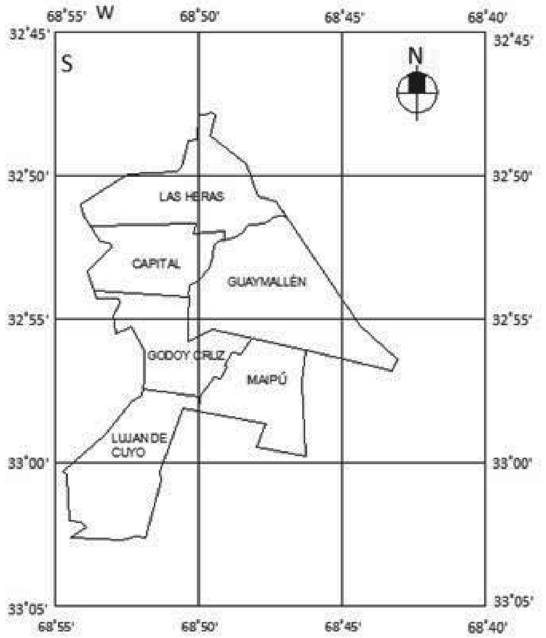

Figure 2: Municipalities in Mendoza city and surroundings

As Figure 3 illustrates three big deposits zones are distinguished: the alluvial cone, alluvial plain and an area of transition between the cone and the alluvial plain.

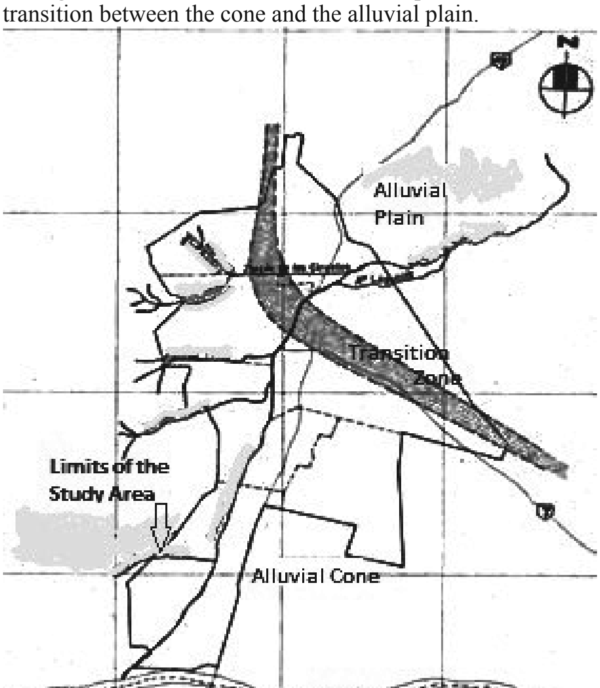

Figure 3: Distribution of superficial alluvial deposits in the study area

The maximum grain size of the sediments decreases from the entrance of the alluvial fan close to the Mendoza River in direction to the NE of the alluvial plain where there are deep fine deposits.

Seventy two geotechnical profiles were modeled in the study. Information not available directly from measurements of unitary weight was obtained through extrapolation equations taking as a basis the information provided by selected profiles (included in Poder Ejecutivo Nacional 1989) and soils studies for foundations validated as reliable (gathered by Barchiesi 2009).

The above information was grouped by related areas and soil type.

Shear wave velocities profiles were assessed through empirical correlation equations based on N-values of standard penetration tests (SPT).

These equations were selected through a process of comparison whose indicator (DVel [%]) was the difference between the values that yield correlation equations (theoretical) and those measured in some profiles, divided by the last one.

Curves of stiffness degradation and damping increase with shear deformation for different soils were taken from the literature taking into account the characteristics of the materials. Barchiesi & Mancipe 2012 describes the abovementioned procedure.

3 SENSIBILITY STUDIES

A sensitivity study to parameters with greater uncertainty that are shear wave velocities and the type of soil as well as its rigidity and damping curves, was performed. The first parameter cited was obtained from correlations with known information and the second was obtained from geotechnical profiles and technical literature. An analysis was also performed to study the influence of the characteristics of the signal input and the type of software used. A synthetic signal obtained from the INPRES 1991 spectrum for soil type 1 and seismic zone 4 was used in the study of sensitivity per signal type. The envelope for this signal was established by similarity with those observed in Mendoza in 1985 and 2006 events. The synthetic signal was obtained from the spectrum by SIMQKE, Gasparini & Vanmarcke 1976. This signal is scaled 0.35g corresponding to the acceleration for null period of the spectrum of the cited regulation (INPRES 1991) for the area and soil type abovementioned. In this sensitivity analysis, the DEEP SOIL nonlinear regime software was applied, see Youssef & Hashash 2011b.

On the other hand a sensitivity study was conducted to evaluate the influence of the type of signal. In this study were considered, in addition to the abovementioned synthetic signal, the following ones: i) a signal corresponding to the study area registered in thick, dense and outcroppings gravels in the Maipú station during the 1985 event, see Bardet et al 2000; ii) a signal obtained in rock in the 1994 Northridge earthquake, see Youssef Hashash 2011a.

In this analysis it was observed that the spectrum corresponding to the abovementioned regulations acts as an envelope for the others (i) and ii)) also mentioned, proving sufficient information to establish maximum seismic loads. That is true even though each signal has associated a spectrum with its own characteristics in terms of maximum acceleration and amplifier periods.

Computer programs used in the sensitivity analysis by software are: SHAKE91 (Schnabel et al 1992) and EERA (Bardet et al 2000) both linear equivalent, DEEP SOIL (Youssef Hashash 2011b) and NERA (Bardet and Tobita 2001) (non-linear). This analysis showed that in coarse soils, spectral shapes and their periods of maximum amplification are similar for all programs, except for the highest values of acceleration for programs in equivalent linear regime. In fine soils, the programs in nonlinear regime displace maximum responses toward the high periods.

Additionally, nonlinear computer programs evidenced great degradation rigidity level associated to significant reductions in maximum spectral accelerations.

In order to evaluate the possible effects of the quality of the curves assumed for the degradation of stiffness (G/G_0 vs. γ) and the development of damping (D/D_0 vs. γ) sensitivity analysis against the first of these parameters were made, adopting greater and lower values than those corresponding to the best possible estimate.

The obtained results show predictable trends and a relatively small influence of these parameters while they choose within reasonable ranges.

Furthermore, rigidity curves lower than best estimates cause greater G modulus degradation, evidenced by lower maximum spectral accelerations and greater associated periods.

On the other hand was observed that in profiles with predominance of coarse soils, if considering an increase in its shear wave velocity with respect to the assumed values, then the spectral amplification diminishes and as an extreme, the spectral form in rock practically is preserved; and inversely if lower stiffness than those assumed according to the best possible estimate, are proposed.

In profiles with predominance of fine soil in the presence of increases in shear wave velocities with respect to the adopted values, spectra move towards high frequencies without increases in spectral acceleration amplifications.

In the presence of diminishing in shear wave velocities was verified the inverse phenomenon and strong reduction in acceleration amplifications associated with larger deformations and damping.

4 ZONATION

Owing to not enough shear wave measurements and geotechnical information directly obtained are available and to the fact that the quantity of available seismic events registers for the study area is small, was not possible to establish design spectra or to generate a seismic micro zoning applied to engineering design.

Because of those reasons the seismic zoning proposed here has a preliminary and advisory character being aimed to future studies that look deeply into the theme.

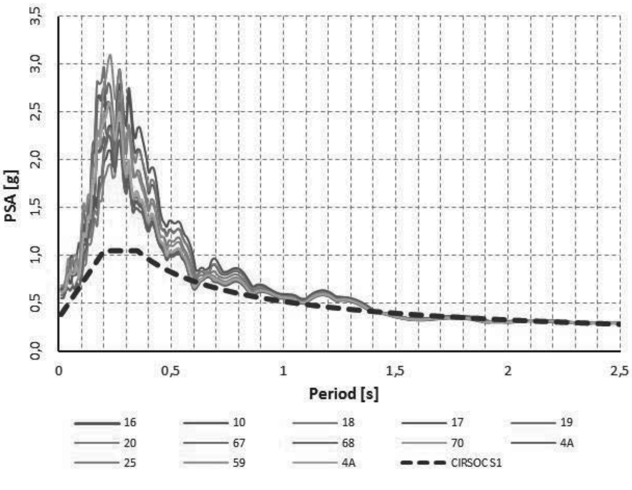

Figure 4: Response spectra, Zone 2, earthquake CIRSOC 103, Ao = 0.35g

Particularly we point out that the seismic zoning presented here was developed only at response level because the development of design spectra is an outstanding work until now. In the same sense comparisons between structural response spectra and earthquake design spectra in Figures 4, 5 and 6 has only an illustrative character being not directly applicable.

In this project 72 geotechnical profiles were modeled. Results led to propose six zones characterized by a typical response spectrum shape.

Figure 7 shows a map whit the preliminary proposed zonation. In the following each of these six zones is briefly described.

In Figures 4, 5 and 6 numeric references correspond to profiles taken from Poder Ejecutivo Nacional 1989; numeric references followed by "A" correspond to profiles taken from Barchiesi 2009 and the references "CIRSOC S1" to "CIRSOC S3" correspond to the spectra for "1" to "3" soil types into the regulation INPRES 1991 according to the studied site.

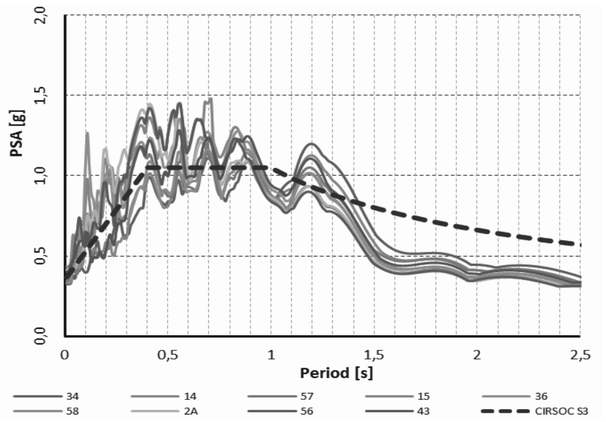

Figure 5: Response spectra, Zone 3, earthquake CIRSOC 103, Ao = 0.35g

Zone 1 showed the following response parameters: $a_{máx}$ = (1.20 ÷ 2g) and T = (0.09 ÷ 0.18s). This zone is located into the area of coarse deposits for the alluvial cone, with predominance of coarse deposits to the south and with the presence of shallow silty layers with 2 to 4m thickness and the presence of deeper profiles with sands and silts associated to piedmont streams.

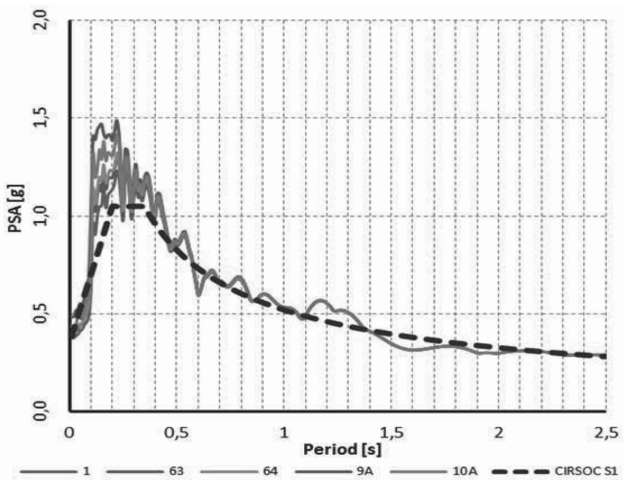

Figure 6: Response spectra, Zone 6, earthquake CIRSOC 103, Ao = 0.35g

Figure 4 shows the spectra of Zone 2, $a_{máx}$ = (2.2 ÷ 3g) and T = (0.19 ÷ 0.30s), corresponding to fine deposits for the Alluvial Cone, with profiles characterized by shallow sands and silts 7 to 10m in thickness overlaying gravels with high shear wave velocity.

Figure 5 shows the spectra corresponding to Zone 3, $a_{máx}$ = (1.1 ÷ 1.38g) and T = (0.45 ÷ 1.00s) with deep fine deposits located into the alluvial plain with strong variable thicknesses between 18 to 42m that lie upon high shear wave velocities gravels.

Zone 4, $a_{máx}$ = (1.80 ÷ 2.20g) and T = (0.34 ÷ 0.45s), corresponds to an alluvial plain sector with fine deposits (silts) 10 to 14m in thick that lie upon high shear wave velocities gravels.

Figure 6 shows spectra corresponding to Zone 6, $a_{máx}$ = (1.15 ÷ 1.40g) and T = (0.09 ÷ 0.20s) with coarse deposits for the alluvial cone that eventually outcrop.

Zone 5, $a_{máx}$ = (2.20 ÷ 2.80g) and T = (0.18 ÷ 0.35s), corresponds to an alluvial plain sector with presence of sandy and eventually silty deposits 5 to 7m in thick that lie upon high shear wave velocities gravels.

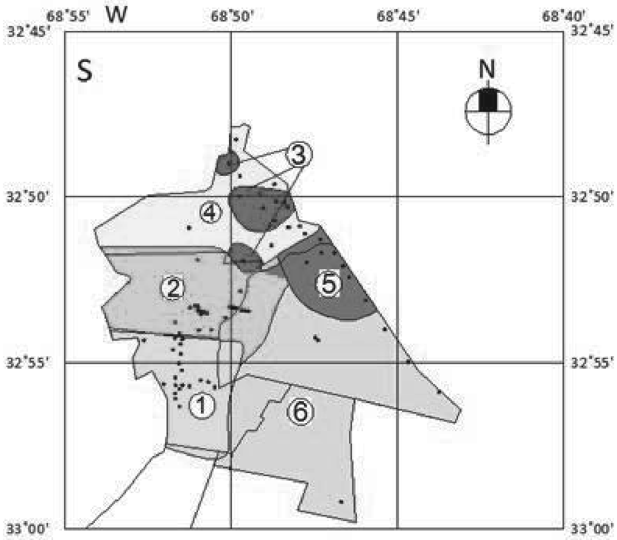

Figure 7: Proposed seismic zoning map

5 CONCLUSIONS

Numeric modeling made evident six zones characterized by its acceleration levels and amplifying periods. These zones run from rigid deposits into the alluvial cone with smaller maximum accelerations values and reduced amplifying periods to fine deep deposits into the alluvial plain with medium maximum accelerations values and high amplifying periods.

The highest accelerations correspond to the fine sediments sector into the alluvial cone that can be associated to high impedance due to high shear velocity (or rigidity) contrasts made evident by the geotechnical profiles.

Sensitivity analysis evidenced that, if an increment in rigidity (shear wave velocity) respect to the assumed values in profiles with predominance of coarse soils is proposed, then the spectral amplification diminishes and in extreme practically maintain the original spectral form in rock and inversely, if lower rigidities than the assumed ones are proposed.

For fine soils profiles in the presence of increments in rigidity (shear wave velocity) respect to the adopted values, spectra move to high frequencies without increments in acceleration amplifications. In the presence of rigidity decrements the inverse phenomenon was verified as well as a strong reduction in acceleration amplifications that are associated to greater deformations and damping.

For certain, the most relevant conclusion for the study has consisted in verifying the presence of very strong seismic site effects as well as into the necessity to intensify the studies with the aim to arrive to a proposal for an actualized and well founded seismic micro-zoning for Mendoza city and its surroundings.

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