THE POSSIBLE INFLUENCE OF SOILS CONDITIONS ON EARTHQUAKE EFFECTS: A CASE STUDY

J. C. CASTANO [1], J. L. ZAMARBIDE [2], I. ARANGO[3] and M. A. BUFALIZA[1]

1 National Institute of Seismic Prevention
Roger Balet 47 Norte, 5400, San Juan , Argentina

[2] National University of San Juan
San Martín 1109 Oeste, 5400, San Juan, Argentina

[3] Bechtel Corporation
P.O. Box 193965, San Francisco, California 94119-3965

Paper No. 1068. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

ABSTRACT

On January 26, 1985, a magnitude $m_b = 6.0$ earthquake, affected Gran Mendoza causing extensive damage, mainly to adobe construction, but only five casualties. The epicenter was located at approximately 30 km from the center of the city, which is the most important urban aglomerate of western Argentina. Damage distribution was not uniform, which was confirmed by observed intensities varying between VI and VIII MM in short distances.

Two types of subsoil conditions prevail in the studied area: shallow stiff soils and deep soils. Both types of soils were accurately known from the information provided by many drillings, several surface geophysical measurements, conducted during a previous study, and microtremor studies. Detailing damage surveying was done and damage indices were defined from the information provided by it. Strong motion records obtained during this earthquake were analyzed. Peak ground accelerations varied between 0.10 and 0.41 g.

All this information allowed the soil types to be related with damage distribution and strong motion record parameters. The study shows no definitive correlation between subsurface soil conditions and damage indices. However, it appears that spectral motions in excess of about 0.6g were required to trigger the highest damage indices.

KEYWORDS

Peak accelerations; damage indices; soil conditions; adobe construction.

INTRODUCTION

The central west region of Argentina, where Gran Mendoza is located, constitutes the most seismic active area of this country. The tectonic setting results from the west to east subduction of Nazca Plate under the South America Plate. As a consecuence of this dynamic process major structural features have been developed, such as the Cordillera de los Andes and the linear zone of volcanoes. Although these structural features vary spectacularly from north to south, the region where Gran Mendoza lies is characterized by an almost horizontal position of the Nazca Plate. The Precordillera, situated immediately west of Gran Mendoza and east of the main Cordillera, establishes a thrust system formed of deep-rooted folds and reverse faults, which are still active, giving place to several potential seismic sources, some of them going through the urban area. Some of these features reach the eastern part of the region under study and show up at the surface as anticlines or surface thrusts.

The urban aglomerate called Gran Mendoza, where more than 800,000 people lives, includes parts of six departments (Las Heras, Guaymallén, Capital, Godoy Cruz, Maipú y Luján) of Mendoza Province (Fig. 1), in an area of 500 km^2. Several destructive earthquakes affected this urban center. From all of them, the 03-20-1861 earthquake rises above the rest because it is still the most destructive one of Argentina. It destroyed Gran Mendoza, killing 6,000 people in a population of 18,000.

The 01-26-1985 earthquake was the last destructive seismic event to strike Gran Mendoza. Although it had a moderate magnitude, considerable damage occurred in small areas with mostly adobe buildings been affected. For the first time many accelerograph and seismoscope records located in the high density population area were obtained. This information, together with soil explorations and tests carried out lately, allowed a correlation between three very important components of the seismic problem: strong motion characteristics, soil types and structural response.

THE JANUARY 26, 1985, MENDOZA EARTHQUAKE

On January 26, 1985, few minutes after midnight (03:07:00.2 GMT) a moderate magnitude earthquake (m_b=6.0) struck Gran Mendoza area, killing five people and causing spread severe damages, especially to the non earthquake resistant constructions and also socio-economical consequences, due mainly to the fact that its epicenter was located very near to the city of Mendoza (15 km to the south of Gran Mendoza border). More than 300 aftershocks with depths variable between 3 and 30 km, were recorded during the 30 days subsequent to the main shock.

Several accelerographs recorded this event, five of them located within the Gran Mendoza area. Peak accelerations ranged from 100.0 to 408.5 gal. Although high values of peak acceleration were recorded, the duration of the significant portion of the records (a_{max} > 50 gal) did not exceed 4 sec. (Fig. 1). In addition to this, several seismoscope records were obtained, from which the maximum seismic coefficients were computed.

This earthquake, although it had a relatively low magnitude produced very important effects over constructions. The damage occurred only in buildings; no damage to the infrastructure (bridges and similar civil constructions, roads, water networks, etc.) was observed or reported. The distribution of the damage was not uniform. Gran Mendoza reached an average intensity of VII MM but there were small zones with greater values than VIII MM. Damage varied widely depending upon the type of construction under consideration. From the total number of constructions existing in Gran Mendoza at the time of the earthquake, 36% were non earthquake resistant, and were mostly adobe dwellings (Banco de Información Catastral, 1987). The typical damage to the adobe buildings were: collapse of some walls due to seismic loads normal to them; cracksand/or disjointing of walls in the corners; diagonal cracks in walls with openings; separation between lintels and the rest of the wall; downfall of cornices; etc.. The same type of damage was reported for mixed buildings (adobe and brick). The separation between adobe walls with brick walls, which generally constitutes the facade, was repeatedly observed. In masonry buildings without concrete bonds, damages were less than in adobe ones, but anyway they can still be categorized as significant, especially for those located in the most affected zones. The behavior of the constructions built in accordance with the earthquake resistant code provisions was in general satisfactory. In some cases where damages were observed they were caused by inadequate structural designs.

Extensive damage survey questionaires were analized (over 36,000 of them) which show a rather non-uniform pattern of damage. It was assumed that damage to adobe buildings was representative of shaking intensity due to three reasons: the construction types existing in the area under study, the types of damage caused by the earthquake and the earthquake characteristics. Mixed constructions (adobe and bricks) were included in this category. A Damage Index (DI) defined as the number of adobe structures damaged (seriously or totally ruined) to the total number of adobe buildings in the area was calculated for different locations. In Fig. 2 average damage indices for each department of Gran Mendoza and isoseismal for the

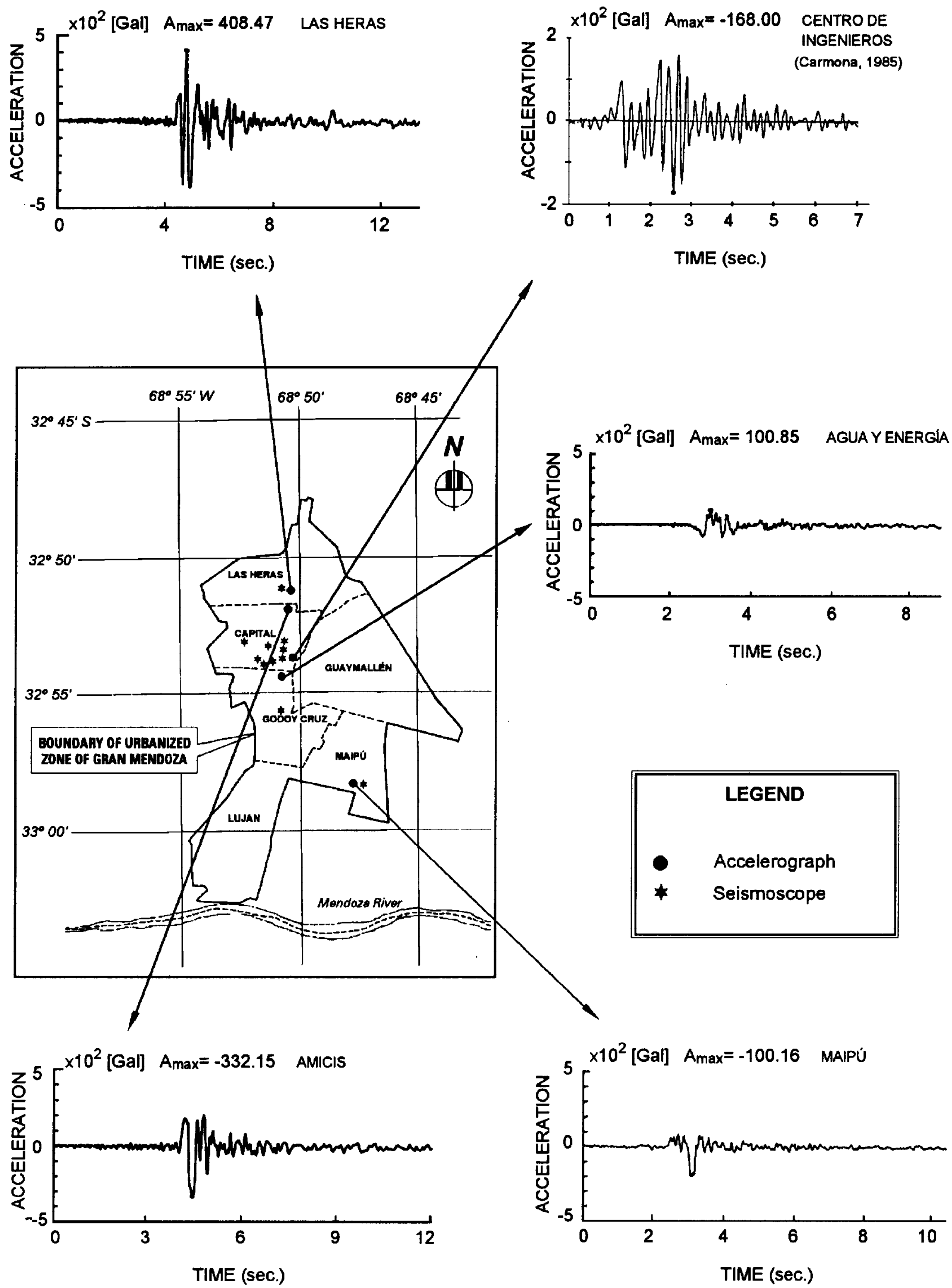

Fig. 1. Strong motion instruments locations within the Gran Mendoza area and accelerograms of the January 26, 1985, Mendoza earthquake

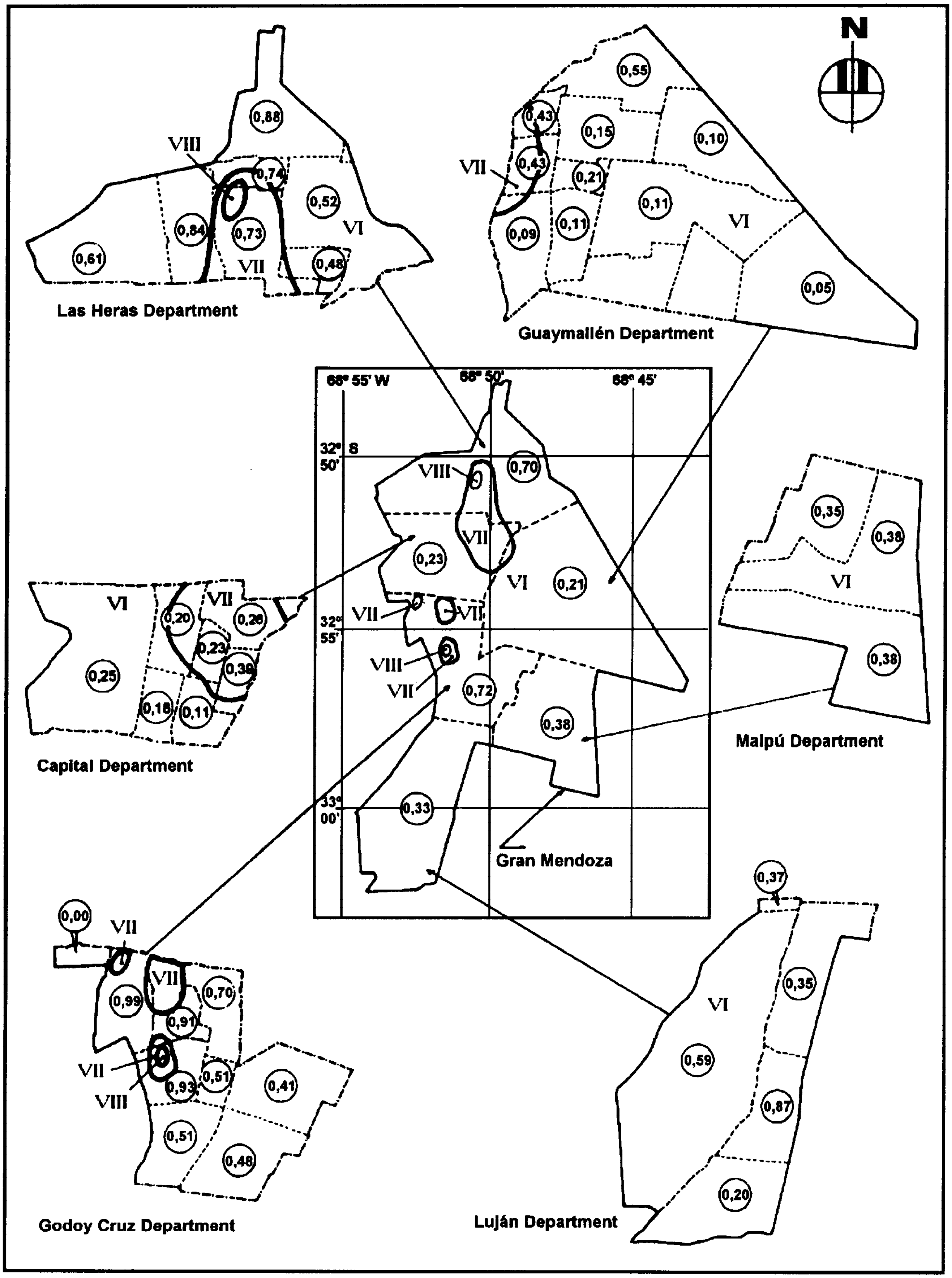

Fig. 2. Damage indices and isoseismal curves for the January 26, 1985, Mendoza earthquake.

01-26-85 Mendoza earthquake are presented. Also are shown the damage indices for the different districts of each department. As can be seen, there is a good agreement between the intensity values obtained after quick observations done immediately after the earthquake and the damage indices determined through a detailed analysis of the damages surveyed case by case.

SUBSURFACE SOIL CONDITIONS IN THE AREA

The spatial distribution of soils in the study area was defined through extensive geophysical, boring and microtremors studies. Two well defined geologic units are distinguished: the coarse alluvial fan deposits of the Mendoza river (or so called Cono de Maipú), which covers the south and southeast portion of Gran Mendoza and the alluvial plain (called Tulumaya plain) consisting of finer sediments to the north and northeast of the same area (Fig. 3). The western portion of the area under study is situated within the ends of the Mendoza piedmont zone. These sediments came from the west and they are interbedded with the deposits of the Mendoza river alluvial fan in a narrow band directed north south. The demarcation between the coarse and finer deposits to the north is not a well defined line, but rather gradual within a wide zone, which is called transition zone. The thickness of the silty materials overlying the Mendoza river alluvium is rather small in the southern part of the area under study, being generally of the order of 1 to 3 meters. It increases gradually to the central and northern zones as was observed, reaching 20 meters at the location of some of the exploratory boreholes. In fact, northeast of Las Heras and north of Guaymallén, silt and clay deposits thicker than 20 meters predominate. Typical fine-sediments thickness within the transition zone would be expected to range between 5 and 20 meters.

Results of standard penetration tests show, that in general, the alluvial sediments within the area vary in their compaction from dense to loose (Fig. 3), as described below:

° The coarse grained deposits of the Mendoza river alluvial fan, show medium degrees of compaction in the first 2 to 3 metres depth, and from these depths downward are dense to very dense. The same situation has been detected in the coarse granular sediments coming from the western Mendoza piedmont.

° The fine sediments, such as silts, sandy silts and clayed silts, which cover the pebbles, gravels and sands of the piedmont and the alluvial fan deposits with several thicknesses, show variable degrees of compaction, from very loose to medium.

It is well known that in coarse granular soils the presence of cobbles, pebbles and coarse gravels does not allow to carry on the tests mentioned above. For this reason, the relative density in these soils was estimated on the basis of results of geophysical tests (down-hole and surface refraction), which were carried out also in the other soils, in order to confirm the inferences made from the results of standard penetrations tests.

For a site classification, a series of one-dimensional site response analyses were conducted using a set of 17 soil profiles representative of the soil conditions found in the Gran Mendoza. For the analyses, the computer program SHAKE (Schnabel *et al.*, 1972) and accelerograms recorded at rock sites were used. Profile 1, which consists of 2 meters of soil over dense gravel was considered stiff soil. Being this profile the reference one, ratios of the computed surface response spectra for Profiles 2 through 17 to Profile 1 were obtained.

To obtain further information microtremor studies were carried out in the area (INPRES-CISMID, 1993). The isoperiods obtained in the area are in agreement with the results mentioned above.

From these studies a site conditions classification will be adopted which is similar to the one proposed in a previous microzonation study (INPRES, 1994), which differentiates two categories as follows: a) Rock and Stiff Soil: Subsurface conditions consisting of shallow deposits of silt and fine sands with thickness from 0 to about 20 meters, underlain by rock, or dense to very dense piedmont or Mendoza river gravelly deposits, and b) Deep Soil: Subsurface conditions consisting of fine sands and silts, and stiff clays extending 20 meters or more below the ground surface, underlain at greater depths by very dense deposits of Mendoza river gravels or rock.

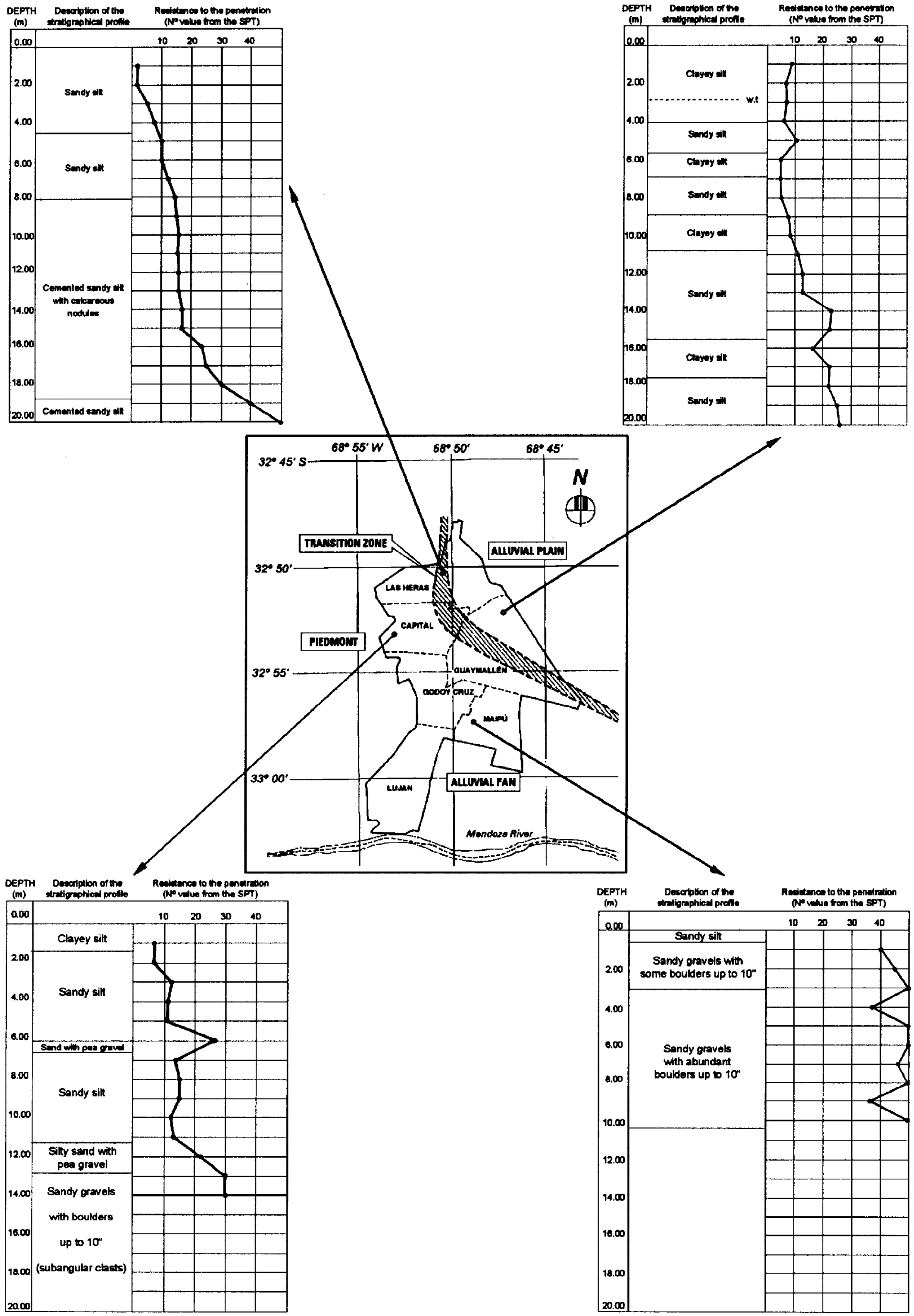

Fig. 3. Distribution of the subsurface conditions within the Gran Mendoza area and some significant results from standard penetration tests.

SUBSOIL CONDITIONS, STRONG MOTION PARAMETERS AND DAMAGE INDICES: THEIR POSSIBLE CORRELATION

Earthquake damage distribution (Fig. 2) does not show a clear correlation with subsurface conditions (Fig. 3). In some zones such as Godoy Cruz there was a concentration of damage which can not be explained in terms of the simple shallow stratigraphy. Additional geotechnical investigations were performed after the earthquake by means of drilling in this area (Fig. 4). The results showed no evidence to allow a relation between damage and subsoil characteristics. This is in agreement with the results obtained in previous studies which have indicated that peak ground acceleration values are relatively insensitive to subsurface conditions with the exception of soft soils (Joyner and Boore, 1981).

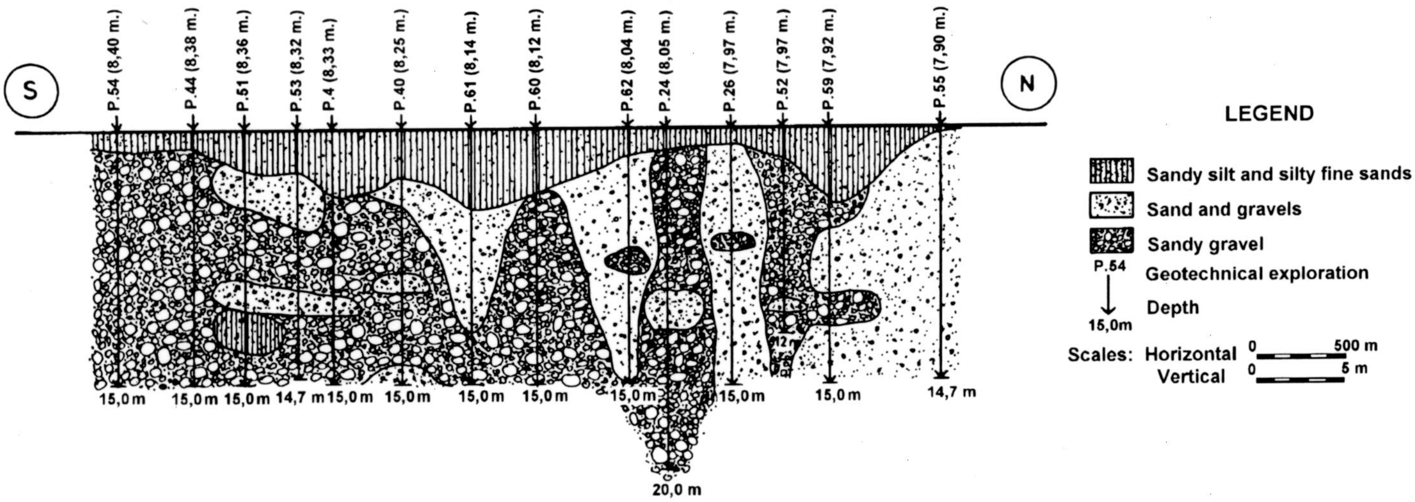

Fig. 4. Typical soil profile from the Godoy Cruz zone.

The seismoscope records obtained during the 1985 Mendoza earthquake also show the variability in ground shaking that may occur over short distances. Such instruments were located at distances of no more than one kilometer in central Mendoza, at sites with very similar soil conditions: a few meters of silty soil over dense gravel deposits. The great difference between some peak amplitudes (relation 2:1) may be partly due to differences in building response, but it demonstrates that large differences in ground motion can occur over short distances for sites with similar subsurface conditions.

This randomness of ground motions had been explored in more detail by Abrahamson (1988) in an analysis of the ground motion data from the SMART1 array in Taiwan. SMART1 consists of a dense array of accelerographs located on an alluvial plain with uniform soil stratigraphy. From an analysis of the variance in recorded peak accelerations for individual earthquakes, the author concluded that variations in peak accelerations of $\pm$ 20% over distances of a few kilometers for identical site conditions can be expected.

The information provided by the records obtained at seven sites located within Gran Mendoza, which were recorded during the 01-26-85 earthquake is summarized in Table 1 (Zamarbide and Castano, 1993). This Table includes site characteristics, epicentral distances, damage indices, spectral amplifications, and spectral accelerations corresponding to T = 0,15 seg and 0,05 damping. This period was selected because is the most representative of natural period of adobe buildings in the area. The spectral amplification for T = 0.15 sec. corresponds to the average of both horizontal components, with the exception of that corresponding to Agua y Energía location, in which only one component was recorded. Peak accelerations for two of these sites (♦) were estimated from the records of the seismoscopes installed there, by means of a relation between peak acceleration and the maximum seismic coefficient of the seismoscope (c_s): $a_{max} = 1.36\ c_s$.

A good correlation between peak accelerations and damage indices is observed, but no dependence between peak acceleration and subsoil characteristics is noted. The above results indicate that the local site conditions within the study area should have only a minor effect on the short period ground motions and that significant variability may occur during individual events. Therefore, in the light of the results of the investigations carried out during this study, it cannot be asserted that there is a correlation between the distribution of damages and the subsurface characteristics of the studied area.

Table 1. Summary of the data provided by accelerographs located in the Gran Mendoza area

Accelerograph location		Epicentral	A_{max}	Spectral values for T = 0,15 s		Damage	Site characteristics		
Building	Department	Distance (km)	(gal)	Amplification	Acceleration	DI	T_{pred} (sec)	Stratigraphy	Geomorphological unit
Municipalidad	Las Heras	31	408.5 (T)	2.13	870.1	0.73	0.30	> 20 m of silts and sands over gravels	Transition zone
Esc. D'Amicis	Capital	29	332.1 (T)	2.13	707.4	0.50	0.22	c. 13 m of silts over gravels	Transition zone
A. y Energía	Capital	26	100.9 (L)	2.00	201.8	0.40	0.25	c.7 m of silts and sands over gravels	Alluvial fan
Municipalidad	Maipú	15	190.2 (T)	2.20	418.4	0.38	0.11	c.3 m of sands over gravels	Alluvial fan
Co. Ingenieros	Capital	26	168.0 (T)	2.40	403.2	0.25	0.22	c. 10 m of silts and sands over gravels	Alluvial fan
U.T.N. - D.N.V.	Capital	27	250.0 ♦	-	-	0.18		c. 1 m of sands over gravels	Piedmont
Municipalidad	G. Cruz	24	500.0 ♦	-	-	0.80		c. 2 m of sands over gravels	Alluvial fan

CONCLUSIONS

The strong motion instruments which provided the records obtained during the Mendoza earthquake of January 26, 1985, were located at sites with differente subsoil conditions and in the most densely inhabited zone of Gran Mendoza. The records show high values of peak ground acceleration but very short duration. The resulting damages, mostly in adobe constructions are in accordance with the characteristics of this earthquake, except for the Godoy Cruz area. The behavior of the constructions built in accordance with the earthquake resistant code provisions was in general satisfactory, although damages in non structural elements in some tall buildings were observed. There were few buildings that suffered structural damage, due mainly to poor structural designs or construction faults. The study shows a good correlation between recorded peak accelerations and damage indices. However, no definitive correlation between subsurface soil conditions and damage indices was observed. It appears that spectral values in excess of about 0.6 g , which were observed at localities within the transition zone (Table 1) were requiered to trigger the highest damage indices.

REFERENCES

Abrahamson, N.A. (1988). Statistical properties of peak ground accelerations recorded by the SMART 1 array. *Bull. Seism. Soc. Am.*, 78, n. 1,. 26-41.

Banco de Información Catastral (B.I.C.) (1987). Dirección Provincial de Catastro, Mendoza.

Carmona, J.S., (1985). Terremoto del 26 de Enero de 1985. Sus requerimientos a los edificios de Mendoza. *Revista CENTRO*, **67**, 39-53.

INPRES-CISMID (1993). Estudio de Microtrepidaciones en la Ciudad de Mendoza. Informe Final. Laboratorio Geotécnico CISMID-UNI.

INPRES (1994). Microzonificación Sísmica del Gran Mendoza. *Publicación Técnica*, **19**, INPRES, San Juan, Argentina.

Joyner, W.B. and D. M. Boore (1981). Peak horizontal acceleration and velocity from strong-motion records including records from the 1979 Imperial Valley, California earthquake. *Bull. Seism. Soc. Am.*, **71** (6), 2011-2038.

Schnabel, P.B., J. Lysmer, and H.B. Seed (1972). SHAKE - a computer program for earthquake response analysis of horizontally layered sites. *Report N° EERC 72-12.*

Zamarbide, J.L. and J.C. Castano (1993). Analysis of the January 26, 1985, Mendoza (Argentina) earthquake effects and of their possible correlation with recorded accelerograms and soil conditions. *Tectonophysics*, **218**, 221-235.