MICROZONATION STUDIES IN ARGENTINA

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ABSTRACT

Seismic Microzonation of two urban areas in the centralwestern part of Argentina is presented in this paper. The scope of both works and the results are described. Differences between both studies are discussed and future research needs are presented.

INTRODUCTION

The northwestern and centralwestern parts of the argentine territory have been subjected to many moderate to large earthquakes. Some of them have caused several damages to cities within the area.

Accordingly the macroseismic activity distribution in Argentina is based on historical information available (2) and is reflected in the seismic zonation map of the country (Fig.1) which has been used for the earthquake resistant regulations enforced (5).

Figure 1 shows that the highest seismic hazard zone includes two provinces, San Juan and Mendoza, located at the centralwestern part of Argentina along the eastern flank of the Andes. Within the province of San Juan there is the Tulum Valley and within the province of Mendoza there is an urban complex called the Gran Mendoza which constitute the most important centers of economical and social development.

Both regions have been subjected to destructive earthquakes among which it can be mentioned the 1944, 1952 and 1977 earthquakes for the Tulum Valley and the 1861, 1927 and 1985 earthquakes for the Gran Mendoza.

Considering the high seismic hazard of these zones and the risk it implies for the inhabitants life and personal properties, the Federal Government decided to carry out two seismic microzonation studies for these zones through the Instituto Nacional de Prevención Sísmica (INPRES). Both works were performed by private consultants and supervised by INPRES.

The results of these investigations were based principally on the analysis of data referring to four main fields of study: geotectonic, seismology, soil engineering and the existing constructions in the area. These results allowed to achieve the principal aims of this type of investigation, which were materialized in several maps, where the areas under study are divided in equal-hazard zones. The final zonation maps have different destinations: a) zonation maps for structural design purposes,

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to be included in building codes; b) seismic hazard zonation maps for development plannings; c) probable damages zonation maps for emergency plans.

The seismic microzonation of Tulum Valley was conducted between 1981 and 1982 (4) and it covers an area of about 2,200 Km^2 (Fig. 2). The seismic microzonation of Gran Mendoza was conducted between 1987 and 1989 (3) and it covers and area of about 185 Km^2 (Fig. 3). In both cases the areas were selected comprising the main urban centers into the region to be studied and the limits were established by means of elements very easy to be recognized, such as highways, avenues, etc.

SCOPE OF THE WORKS

The main objectives of these studies were:

a) To identify and characterize potential seismic sources.

b) Review of regional historical seismicity.

c) Evaluation of subsoil conditions and its dynamic response.

d) Assessment of diferent seismic hazards in the region.

e) To identify areas of high liquefaction potential.

f) Proposal for zonation.

g) Survey of existing constructions. Identification of their earthquake resistant ability.

h) Formulation of damage and risk criteria and assessment of probable potential losses.

a) Identification and characterization of potential seismic sources

The Tulum Valley and the Gran Mendoza regions are located in a tectonic setting that has been produced by ongoing subduction of the Nazca plate eastward beneath the South American plate.

The subducted Nazca plate changes dip between 26° S and 28° S, north of the province of San Juan, to a near-horizontal subduction. The sub-horizontal aspect is maintained until 33° S, where the city of Mendoza is located and the Nazca plate rapidly resumes a steep eastward dip.

The eastward movement of the Nazca plate at such a shallow depth develops a stress regime on the South American plate, which is actively deformed along its broad western margin, resulting in active geologic structures, some of which are seismic sources in and around the Tulum Valley and the Gran Mendoza regions.

So, there are two sets of seismic sources that originate a significant seismic hazard in the study regions. These are crustal faults within the South American plate and deep seismicity occurring within the subducted Nazca plate. There is a distinct separation between earthquake activity in the crust to a depth of about 40 kilometers and subcrustal earthquake activity at depths between about 100 and 130 kilometers.

The principal performed tasks for the identification and characterization of seismic sources on both studies included compiling of geologic maps of the region, interpreting lineaments from satellite images, performing regional aerial and terrestrial reconnaissance to identify structural alignments, excavating and logging trenches across known and suspected faults, dating of samples to estimate the ages of geologically young data that are faulted, etc.

b) Review of regional historical seismicity

Although the earthquake history in this region has only a few centuries long, it provided important information that was used to augment the geological studies of past earthquakes in characterizing potential seismic sources, also the study of earthquakes in detail provided useful information for the interpretation and analysis of other results like those obtained on the evaluation of the liquefaction potential of soils. For most of these earthquakes their intensity distribution (MMI) were determined and their corresponding isoseismals plotted (2, 3, 4). The principal performed tasks for the review of historical seismicity included compiling of historical earthquakes catalogs introducing data from national and international sources of information, interpreting historical and regional seismicity data using computer-generated maps and cross sections in terms of associations between historical sismicity and geologic structures, and estimating the regional and local seismicity parameters.

c) Evaluation of subsoil conditions and its dynamic response

This point included compilation of existing data, geotechnical explorations, field determinations and laboratory tests, in order to determine the stratigraphic and geotechnical characteristics of the region.

The compilation was made of the available existing information in governmental institutions from all the wells drilled in both provinces, either for irrigation or for potable water supply. In order to complete the above information and to determine the geotechnical characteristics of both areas, the subsoil was studied with explorations open pits, or by manual borings drilled with circulation of bentonitic mud or by rotary drilled wells, with circulation of bentonitic mud or by bailing.

The explorations allowed: to determine the stratigraphical subsurface section and the water table (in those places where it was reached); to collect samples in the different drilled soil layers, necessary for performing laboratory tests for the identification and classification of the soils; to carry out standard penetration tests (SPT) at every drilled or excavated meter. In order to evaluate the relative density of coarse granular soils, other methods such as the geophysical testing technique was needed.

Also, dynamic analysis of ground response using SHAKE program, for characteristics subsoil profiles of both zones were made.

d) Assessment of different seismic hazards in the region

The assessment was made by evaluating the likelihood that various levels of ground motion will be exceeded at a site during a specified time period, due to the occurrence of large earthquakes, incorporating the uncertainties in selecting the appropriate models of earthquake generation and models parameters required arising from limited data and/or alternative interpretations of the available data.

Attenuation relationships for the ground seismic intensities, considering the source characteristics, the regional characteristic of seismic wave propagation and the local site conditions were determined.

The analysis results were presented on maps which show the variation in seismic hazard throughout the study regions in terms of ground seismic intensities for different probability levels.

e) Identification of liquefaction potential areas

To identify liquefaction potential areas, the potential for the occurence of liquefaction was determined as a function of the **liquefaction susceptibility** and **liquefation opportunity** of the studied areas.

The liquefaction susceptibility of soils was measured using the current empirical correlations between soil penetration resistance and the level of cyclic stress ratio required to cause liquefaction (8, 9). The liquefaction opportunity was measured on the basis of frequency of occurrence of different peak accelerations levels and of a simple correlation between peak ground acceleration and induced cyclic stresses (7).

f) Proposal for zonation

From the seismic hazard analysis the likelihood of exceedance of different levels of peak ground instrumental acceleration during a specified time period was determined at every place within the areas under study. Considering the potential level of acceleration adopted for structural design purposes and the subsoil conditions, zonation maps concerning the design of structures and the corresponding design spectra were presented for both regions.

The delimitation of each zone within the region has been made taking perfectly identificable elements as reference points, such as roads, streets, railway-tracks , etc., with the purpose of practical application and to avoid doubts concerning the situation of the possible construction with respect to the boundary line.

g) Survey of existing constructions. Identification of their principal characteristics

This stage of the study followed the principal aim of determining the earthquake resistant characteristics of the constructions existing in the investigated areas and evaluate their vulnerability, that is, the probable losses level that the construction should suffer under the exposure to the determined seismic hazard.

On the basis of this purpose it was intended to have the maximum information from official sources, referred to the different types of buildings existing in the area, which later should be compared and completed with the results from a survey specially developed for both studies.

For the evaluation of structural safety of constructions against seismic forces, they were grouped in earthquake resistant and non-earthquake resistant constructions, considering the existing type of construction in the areas and their behavior during earthquakes.

The results allowed to determine for every urban complex within the studied areas the amounts and percentages of earthquake resistant and non-earthquake resistant constructions.

h) Formulation of damage and risk criteria and assessment of probable potential losses

This point has the objective of developing a technique which would permit to estimate qualitatively the **damage potential** in the areas, taking into account, in a combined way, the most probable peak level of the ground motion for a given time period, the subsurface conditions and the type of construction.

Considering the general objectives of this type of projects, damage in both studies, was associated with the building total collapse and/ or partial collapse of structural elements whose failure affects severely the structure, and might comprise the inhabitants life.

In order to estimate the potential damage, the most adequate amplitude ranges for representing the ground motion severity were selected. This selection was made on the basis of the geological investigation, historical seismicity, the seismic hazard analysis for the probability of exceedance adopted, and on the estimated actual behavior of the existing constructions in the areas.

Once the construction have been categorized as it was presented above, the potential damage associated to each type of construction, for a given set of ground motion and subsurface conditions, was estimated through a direct relationship between motion severity and damage.

This relationship determination was based on the experience from several past destructive earthquakes which occurred in the region, also it was considered the behavior of similar constructions sited on another seismic zones with similar subsurfaces conditions.

In order to simplify the results interpretation, the following classification was stated to categorize damage potential.

DB = Low damages: 0 to 5% of the constructions will undergo partial or total collapse.

DM = Moderate damages: 5% to 25% of the constructions will undergo partial or total collapse.

DI = Important damages: 25 to 50% of the constructions will undergo partial or total collapse.

DA = High damages: 50 to 75% of the constructions will undergo partial or total collapse

DMA= Very high damages: 75 to 100% of the constructions will undergo partial or total collapse.

The results were summarized on maps where the potential damage for each department or division within the studied zones was presented.

ANALYSIS OF RESULTS

Seismic Microzonation of Tulum Valley - San Juan -

Based on geological and seismological information six potential crustal seismic sources have been identified in this region. The maximum credible earthquake for one of the sources was estimated of magnitude (Ms) 7 1/2, for four of them of magnitude (Ms) 7 3/4 and for the other one of magnitude (Ms) 8. The estimated recurrence intervals for these maximum credible earthquakes range from 250 to 15000 years. For the Benioff zone, lying at a depth of approximately 100 Km beneath the province, the maximum credible earthquake was estimated of magnitude (Ms) 7 1/2 with a recurrence interval of 15000 years/1000 Km^2. At the seismic hazard analysis this source was consider as a horizontal plate model at 100 Km beneath the province.

For a better accuracy on the above studies the historical earthquake record in the vicinity of the province was also analysed. For this project a historical earthquake catalog was prepared using world-wide data sources (11) and all the available earthquake data, from 1917 to 1980, for Argentina, prepared by INPRES.

From the geological, geotechnical, and geophysical studies of the soils and subsurface conditions in the area, three distinct zones were defined for this project (Fig. 4).

The first zone is the alluvial fan of the San Juan river in the western part of the city of San Juan. These deposits consists of dense to very dense coarse-grained gravels. The same situation takes place in the alluvial piedmont deposits in the western part of the Tulum Valley.

As typical in any alluvial fan, the material carried by the river becomes less coarse with the distance from the apex of the fan, toward the east of the city to the alluvial plain, where the fine textures dominate. These deposits include sands, silts, and clays with some lenses and pockets of gravel. As it is shown in Fig. 4 between these two zones there is the transition zone where the fine textures begin to dominate: fine sands, silts and clays become more abundant than gravels and fine gravels. This transition is not abrupt but gradual as would be expeted from the processes responsible for their deposition.

To estimate potential levels of maximum ground motion amplitudes within the studied area, attenuation relationships for ground motion amplitude of crustal and subduction zone earthquakes were estimated (4,12).

The seismic hazard analysis results were presented on maps which show contours of most-probable peak instrumental acceleration for 50 and 100 years period, the acceleration levels with a 10 percent probability of being exceeded in 50 years and contours of return period for an acceleration level of 0.1 g and 0.2 g. Figure 5 shows contours of the most probable peak instrumental accelerations for 50 years period.

The relatively uniform exposure levels within the valley result from two causes, the low rate of attenuation with distance of peak ground motions and the fact that the Precordillera fault dips under the valley. This fault dominates the seismic exposure, hence variations in the source parameters for the other seismic sources will have only minor impacts on exposure levels within the valley.

To identify liquefaction potential areas within the studied region, the probability of liquefaction at points throughout the Tulum Valley for a given period was computed. This probability was obtained considering the empirical correlations presented before, also the seismic exposure analysis and the water table level.

The results indicate that the probability of liquefaction occurring in a 50 year period is generally greater than 50% throughout the irrigated portion of the valley. The uniformity of hazard level results from a uniform level of seismic exposure and a water table generally between 1 and 4 meter in depth. Only slight variations in the mean blow count throughout the valley were observed.

The results of the analysis were used to construct a map of the Tulum Valley (Fig. 6) showing zones of high, intermediate and very low liquefaction hazard. As shown in Fig. 6, the zone of high liquefaction hazard encompasses the area of deep alluvial soils and generally conforms to the irrigated farm lands. The intermediate hazard zone corresponds to the transition zone shown in Fig. 4 and to areas in the valley not currently irrigated. The zone of very low liquefaction hazard consists of the coarse granular soils of the alluvial fan.

The zone of high liquefaction hazard agrees with the areas which showed surface evidence of liquefaction during the 1894 and 1977 earthquakes in the region. It should be recognize that this zone is meant to represent a general level of hazard based on limited soil data. It is expected that within the zone there may be individual sites which have a low liquefaction hazard due to the presence of dense or clayey soils.

To prepare a seismic hazard zonation map for engineering purposes, the map in Fig. 5 of the most probable maximum instrumental accelerations for a 50 year period was selected as the most representative one of ground motion amplitudes, taking into account that at the moment the project was conducted there was a tendency to accept a 50 year return period corresponding to the useful life of the more common constructions.

Figure 5 shows that the three levels of peak acceleration are: amax: 0.35 g; amax: 0.30 g and amax: 0.25 g. Combining this map with those presented in Figs. 4 and 6, the zoning map of Fig. 7 was constructed and it was suggested to be used with purposes of structural design. As it can be observed in the figure, the area under study is divided into three zones. The spectral shapes proposed are presented in Fig. 8.

Before determining the probable losses level that constructions should suffer under the exposure to the seismic hazard determined, a survey of the existing constructions to evaluate their earthquake resistant characteristics was carried out.

For the organization and fulfilment of this task the information from the 1980 Population and Housing National Census was considered as basic data.

Besides, due to the importance of this study and the necessity of getting information in more detaited levels like radios (about 300 dwellings) or segments (15 to 30 dwellings), an exhaustive survey or "a census of every construction" was adopted. Accordingly, 83,683 constructions in the urban populations of the study area were inquired. The general total showed that two types of constructions prevail: the masonry constructions summed up 50,141 i.e. a 59.9 %, and the adobe constructions were 33,255 i.e. a 39.7 %. There were 287 constructions of other types, i.e. 0.4 %.

With respect to the earthquake resistant charactersitics assessed, it could be said that 49,010 constructions (58.6 %) have been classified as earthquake resistant and 34,673 (41.4 %) as non-earthquake resistant. The proportions of constructions of one type or the other vary widely according to the urban populations.

According to the number of stories, the inquiry showed that a 95.8 % belongs to one-storied constructions, a 3.9 % belongs to two- storied constructions and the rest does not exceed 1 %.

Once the constructions were classified, the following amplitude ranges (in terms of peak acceleration) were adopted as the most adequate for representing the ground motion severity: Range 1: 10% g; Range 2: from 10% to 20% g; Range 3: from 20% to 35% g; Range 4: from 35% to 50% g.

For this selection peak accelerations for a 50 year return period were adopted (Fig. 5).

In order to estimate the potential damage it was neccesary to determine a relationship between peak ground acceleration and damage referred to non-earthquake resistant constructions. This relationship was determined making use of the experience from historic earthquakes in the region, specially from the damage analysis of the 1977 Caucete Earthquake, which resulted:

Ground motion vs. percentage of damaged constructions relationship

Type of construction	Ground motion			
	Range 1	Range 2	Range 3	Range 4
Type I: Adobe	0	10%	70%	100%
Type II: Masonry				
a) earthquake resistant	0	0	0	5%
b) non-earthquake resistant	0	5%	50%	80%
Type III: Other types				
a) earthquake resistant	0	0	0	5%
b) non-earthquake resistant	0	5%	50%	80%

In what concerns to earthquake resistant constructions, according to the codes design philosophy, no collapse should take place for any of the selected ground motion ranges. Nevertheless, in order to consider the uncertainty depending on diverse factors which could affect the construction safety (factors depending on the design, construction, materials used, etc.) it was assumed that a small number of construction of this type (estimated in 5% for range 4) would collapse.

The damage potential was determined for each urban complex in the area (Fig. 9) considering the probable range or ranges of the ground motion to which it would be subjected, the characterization of the constructions existing within their boundaries and the damage matrix presented,which gives for each type of construction and for the different ranges of ground motion the probable percentages of damaged constructions.

Seismic Microzonation Of Gran Mendoza

Seven potential crustal seismic sources have been identified as the major contribution to the seismic hazard in Gran Mendoza. The maximum credible earthquake for one of the sources was estimated of magnitude (Ms) 6, for other of magnitude (Ms) 6 3/4, for three of them of magnitude (Ms) 7 and for the the remaining two of magnitude (Ms) 7 1/2 and 7 3/4. The estimated recurrence intervals for these maximun credible earthquake range from 630 to 19000 years. Another source is the subduction zone with a maximun magnitude event of (Ms) 7 1/2 and a recurrence interval of 15000 years/1000 Km^2. Examination of the spacial distribution of seismicity within this source zone indicates a change in both density and focal depth as one proceeds from northwest to southeast across the zone. Accordingly, for the seismic hazard analysis this source was divided into two subzones: a northwestern subzone consisting of a horizontal plate and a southeastern zone consisting of a plate dipping at an angle of 25° to the southeast.

For the historical seismicity analysis an earthquake catalog was prepared using data from two integrated sources. The primary catalog used was the Argentina volume of the SISRA catalog (10). It contains all available historical and instrumental earthquake data for this country, and it draws on all major international data sources.

Data were also added to the catalog from two special studies performed by INPRES. In the first study, portable instruments were operated right after the January 26, 1985, Mendoza Earthquake to locate aftershocks. The second study, conducted from January to August 1987, was a regional microearthquake monitoring study performed by INPRES of the Gran Mendoza region. Both studies provided an accurate focal depth distribution information used to define the characteristic seismogenics depths in the region and also to associate seismic activity to geologic structures.

From all the studies performed in this project to evaluate the subsoil conditions two well defined geologic units were presented in the study area: the coarse alluvial fan deposits of the Mendoza river and the finer sediments deposits of the alluvial plain (Fig. 10). That is, in the southwestern part of the area under study coarse gravels, boulders and large size blocks can be found. The same situation takes place in the alluvial piedmont deposits west of Mendoza city.

As the distance from the apex of Mendoza river alluvial fan or from the piedmont fans increases, the sediments become gradually finer, and consist in gravel, fine gravel and sand, with a surface veneer of silt, clay and fine sands with variable thicknesses up to 20 meters.

In the northeastern part of the zone under investigation begins the alluvial plain where fine sediments such as fine sands, silts and clays which thickness over 20 meters are found.

Based, among other things, on the results of a series of one- dimensional site response analysis carrying on using a set of soil profiles representative of the soil conditions in the area a two site condition classification system was proposed: 1) **rock and stiff soils** and 2) **deep soils** (Fig. 10).

For the seismic hazard analysis attenuation relationships for crustal and subduction zone earthquakes were defined (1,6,13).

The variation in seismic hazard throughout the study region is presented in terms of contours of mean peak ground acceleration level corresponding to 10% probability of exceedance in time periods of 10, 20, 50 and 250 years, for the two site conditions considered.

Peak accelerations corresponding to the above four frequencies of exceedance were interpolated from the computed hazard distributions at each point located on an irregular grid in the study area.

Figure 11 shows contours of peak acceleration level corresponding to 10% probability of exceedance in a time period of 20 years for rock and stiff soils.

The highest hazard levels occur in the vicinity of the Gran Mendoza and along the Barrancas fold (southeastern part of the city) which is characterized as the most active source in the region.

On the basis of the analysis of data obtained from the geothecnical explorations two site condition classifications system was proposed as it is shown in Fig. 10. As it can be observed in this figure most of the urban zone corresponds to the rock and stiff soil zone. The free ground water table is quite deep throughout most of this area, ranging from 35 meters to more than 100 meters which results in a **very low liquefaction hazard potential** zone. However in the northern and northeastern parts of the area under study (deep soils), free ground water table depths range between 1 and 10 meters. The potential for earthquake induced liquefaction was considered in this area because of the presence of saturated, loose fine grained sediments and it resulted that the probability of liquefaction in a 50 year period at any point exceeds 50 %.

Besides, a large part of this northern and northeastern zone has experienced liquefaction during past earthquakes such as the 1861, 1903, 1920, 1927 and 1977 earthquakes.

Thus, the area with shallow ground water and deposits of fine- grained alluvial soils, shown in Fig. 10 as the deep soil zone, was considered as a zone of **high liquefaction potential.**

To prepare a zoning map for structural design within the Gran Mendoza, it was advised to adopt the maximum accelerations for a 10% probability of exceedance in 20 years (Fig. 11) with a frequency of exceedance equivalent to 0.0053 event/year, keeping in mind the current tendency to adopt annual risks in the order of 0.5×10^{-2} to 0.3×10^{-2} for the design of normal constructions in seismic zones.

Figure 11 shows that the three peak acceleration levels are: amax. 0.4 g; amax 035g and amax 030g

For this study an effective acceleration value equal to 0.85 amax was estimated. It was obtained by calculating the average value of the spectral acceleration ordinates corresponding to the 1985 Mendoza Earthquake records for 0.1 sec $\leq$ T $\leq$ 0.5 sec and dividing it by 2 5 which was adopted as the spectral amplitude value. Thus, for structural design purposes three effective accelerations levels were proposed: 0.35 g; 0.30 g and 0.25 g.

As a result of the combination of the maps shown in Figs 10 and 11 and on the basis of the above considerations, the zoning map shown in Fig. 12 was prepared with structural design purposes.

As can be observed in Fig. 12, the studied area is divided into five zones, and it was advised to use the design spectral shapes shown in Fig 13.

To determine the probable losses level of the existing construction in the studied zone a survey was carried out considering the available updated information and the 1980 Population and Housing National Census as basic data. Thus, 9,306 constructions of the total of 138,803 were inquired. This meant to select a sample equivalent to the 6.7% of the total population. This sample selection insured an error margin of 1% with a significance level of 95%.

In what concerns to the earthquake resistant characteristics, it was concluded that 63% of the total are earthquake resistant, while the non-earthquake resistant constructions amount to a 37%.

The proportions of constructions of one type or the other vary from 71% of earthquake resistant construction to 57% as the lowest percentage. The one-storied constructions in the area represent a 96%, which, if the two-storied and three-storied constructions are added, reaches a 99% of the total.

Once the constructions were classified, the following amplitudes ranges (in terms of peak acceleration) were adopted to represent ground motion severity:

Range 1: < 30% g; Range 2: from 30% to 35% g; Range 3: from 35% to 40% g; Range 4: > 40% g.

For the selection peak accelerations with 10% probability of exceedance in 20 years were adopted.

In order to estimate the potential damage a correlation between peak ground acceleration and a damage index for non-earthquake resistant constructions was used. The basic information to obtain this relationship were the records of the accelerograph net and seismoscopes obtained during the 1985 Mendoza Earthquake and the damage observations in those places where the instrumentation was installed (3).

This correlation was summarized as follow:

Ground motion vs. percentage of damaged constructions relationship

Type of construction	Ground motion range			
	Range 1	Range 2	Range 3	Range 4
Type I: Non-Earthquake resistant	30%	45%	55%	70%
Type II: Earthquake resistant	0	0	2%	5%

In order to consider the uncertainty which could affect the earthquake resistant constructions safety, it was assumed that a small number of constructions of this type (estimated in 2% for range 3 and in 5% for range 4 of the ground motion) would collapse.

The probable percentages of damaged constructions were determined following the same procedure presented before. The results are plotted in Fig. 14 for each department of the Gran Mendoza.

FINAL REMARKS

The two microzonation studies already carried out in Argentina have been very important not only for the knowledge of the different subjects related but also for contributing to the earthquake prevention planning within the studied area.

The Gran Mendoza project showed distinctive improvements compared with the Tulum Valley mainly due to the experience gained in this last one, and the available information at the time of the study. Thus, the governmental agencies, the proffessional community and the people in general are the real beneficiaries of the work done.

Although San Juan and Mendoza provinces are the most seismic hazardous in the country, there is an urgent need to extend these type of studies to the northwestern part of Argentina. It is hoped that in the near future this need becomes a reality.

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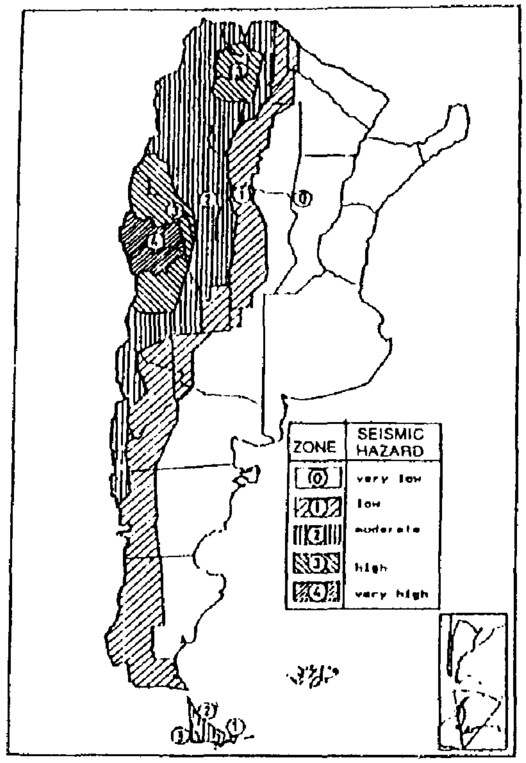

Fig. 1 Seismic Zonation of Argentina

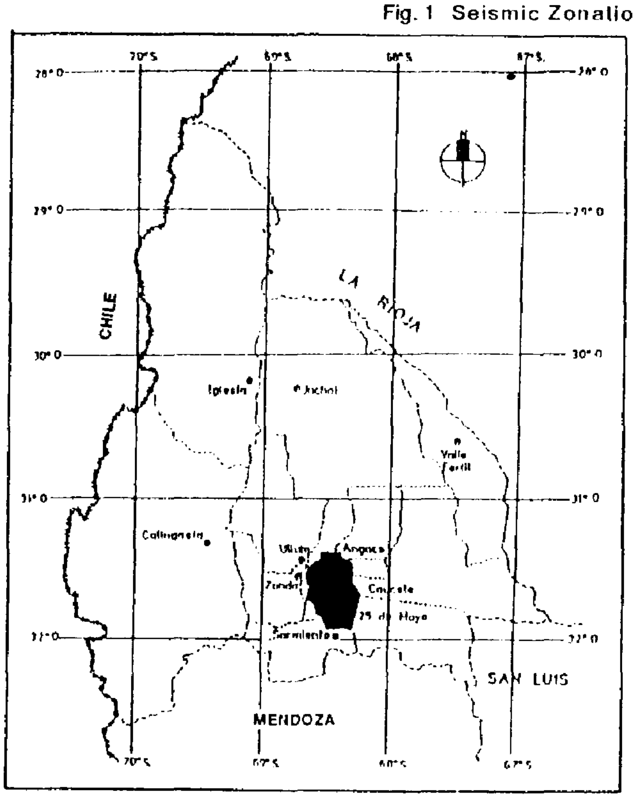

Fig. 2 Location of the studied area in San Juan

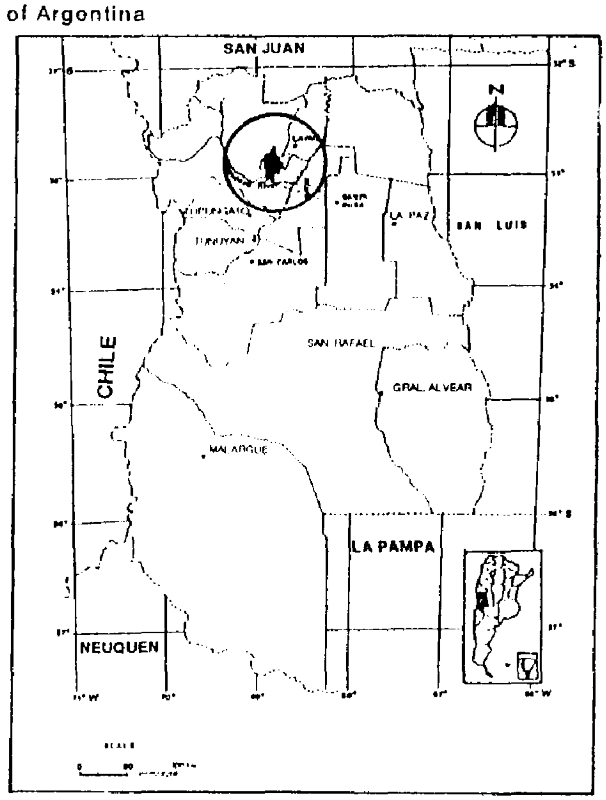

Fig. 3 Location of the studied area in Mendoza

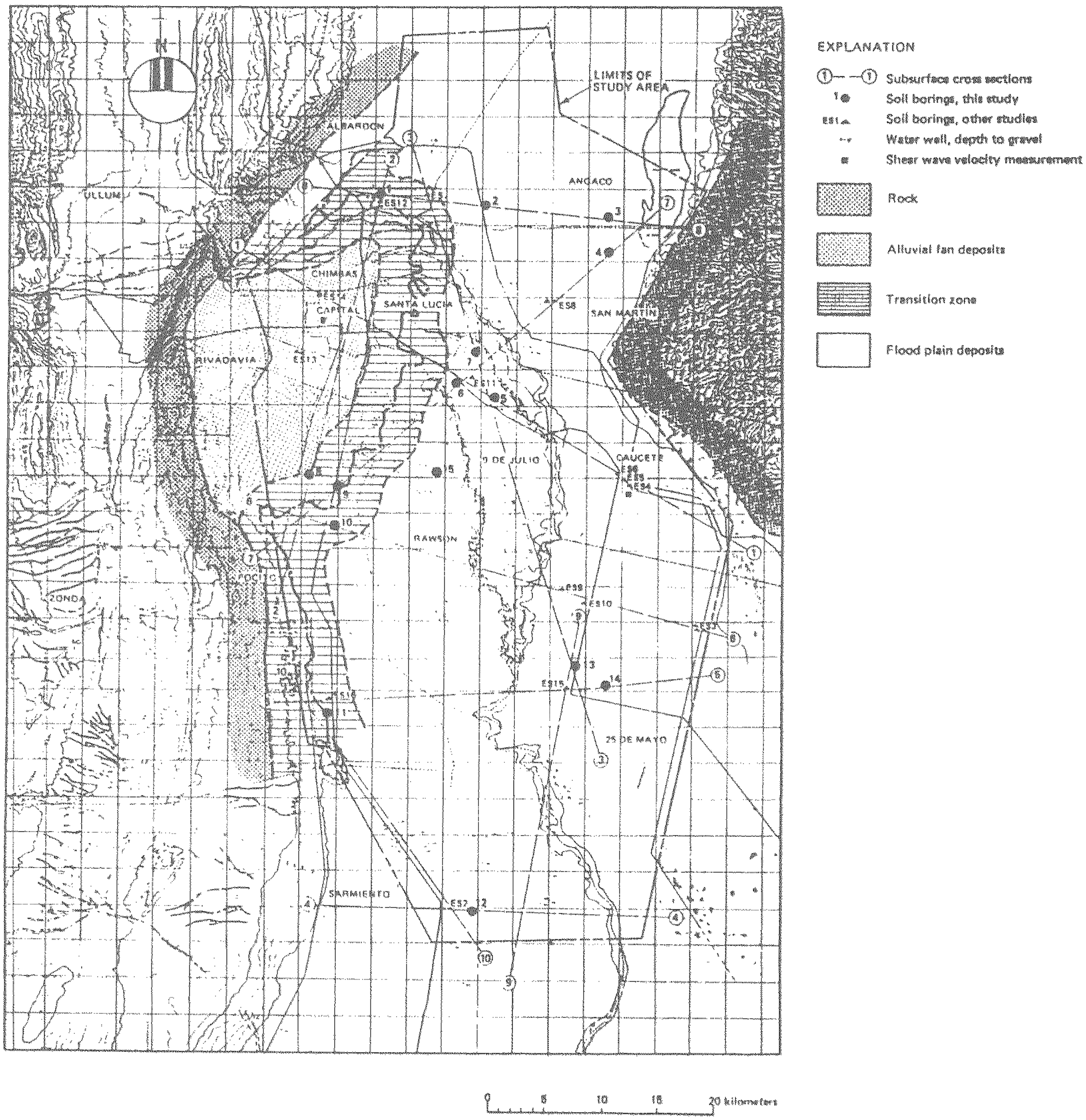

Fig. 4 Tulum valley field investigations and soil conditions

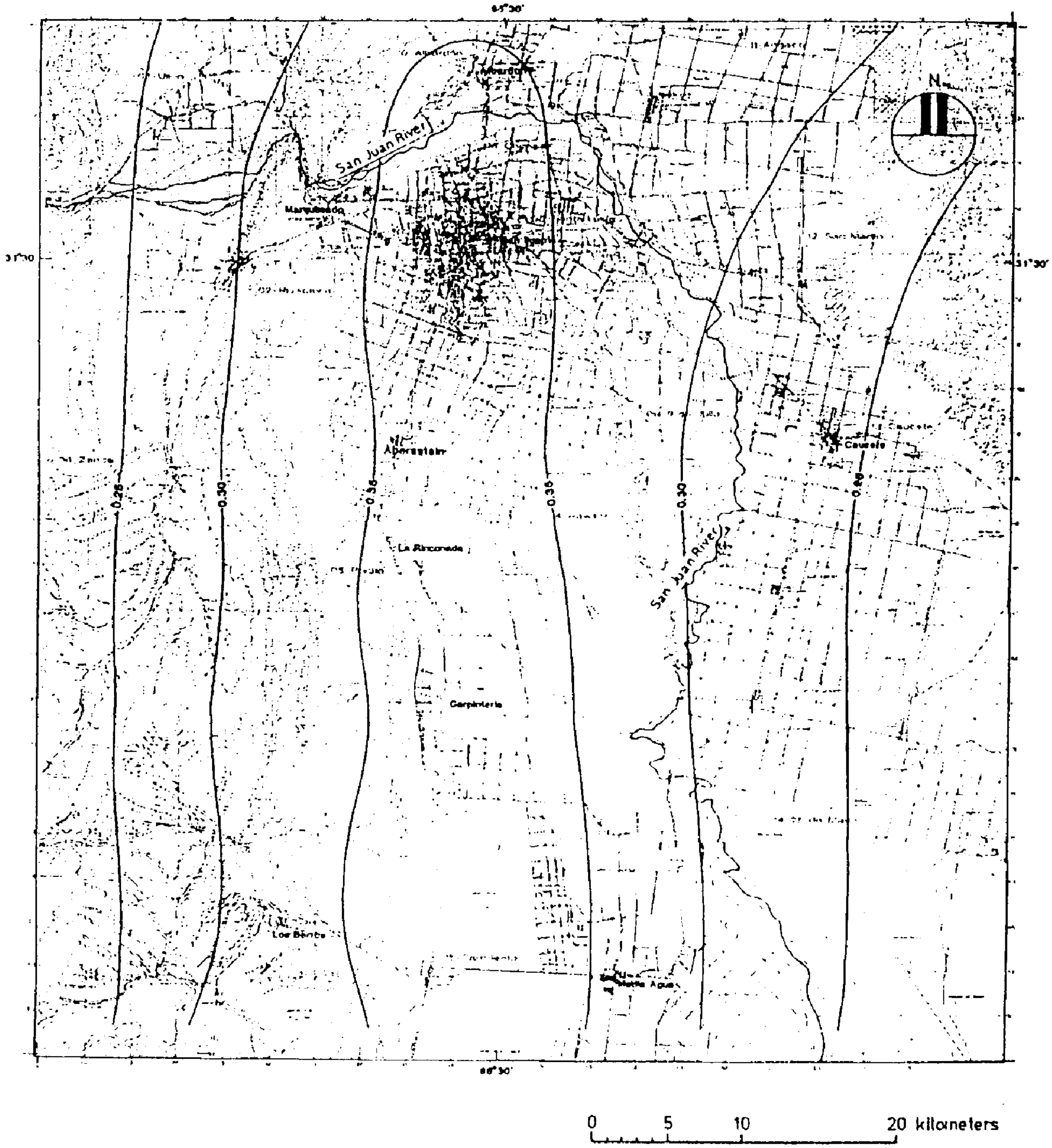

Fig. 5 Tulum valley seismic exposure of most probale peak instrumental accelerations in 50 years