POTENTIAL DAMAGEABILITY DUE TO EARTHQUAKES IN THE TULUM VALLEY, SAN JUAN, ARGENTINA

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SUMMARY

The main purpose of this study is to assess the potential damageability due to earthquake ground motion in existing buildings located on urban areas at San Juan province, Argentina. Identification of potential seismic sources and areas of potential ground rupture, review of historical seismicity, evaluation of ground water conditions, identification of areas of potential liquefaction etc., were considered for seismic exposure mapping. Also a detailed survey of 83,683 existing constructions was conducted. To assess the potential damageability of existing buildings, a direct relationship between ground motion severity and damage is adopted. Ground motion severity is represented by peak ground acceleration related to Modified Mercalli Intensity, while damage by damage ratio defined as cost of repair divided by replacement cost. Finally, probable economics losses are determined by the product of damage ratio and the probability of ground motion level being exceeded in one and twenty five years.

INTRODUCTION

The province of San Juan, located in the central west region of the Argentine Republic along the eastern flank of the Andes, has been the site of a number of moderate to large earthquakes. The Tulum Valley (Figure 1) is the most important zone in the province because it has almost 89% of its population and more than 90% of the provincial economical activity. Many destructive earthquakes have ocurred like the 1944 and the 1977 earthquakes both with magnitude (MS) 7.4. Existing buildings in the area consist mainly in low rise earthquake resistant masonry or adobe construction with a few reinforced concrete buildings located in San Juan city either with framed structures infilled by masonry panels or concrete shear walls. To evaluate in a rigurous way the potential damageability of existing buildings the following factors should be taken into account: type of lateral load resisting sistem, distribution of mass and stiffness either in plan or in elevation, quality of workmanship, non structural elements, etc..The problem is actually very complex and a methodology that could include all these factors is out of the scope of this paper. Thus the approach adopted herein (Ref. 1) is intented to express the potential damageability in a global fashion and the results obtained will be, in the authors' opinion, useful for economic decision making by governmental officials. It is important to point out that, as explained above, existing buildings in the area are mainly low rise earthquake resistant masonry or adobe constructions with no significant

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excentricities in plan nor uneven distribution of mass and rigidity in elevation, therefore an undesirable performance when subjected to future earthquakes is not espected. Accordingly, no correction factors or weight factors will be employ to take into account these features.

SEISMIC EXPOSURE ANALYSIS

The purpose of a seismic exposure analysis is to assess the probability that values of peak ground acceleration may be exceeded at different sites and to identify the seismic sources that have a dominant contribution to the probability of exceedance. The seismic exposure at a point depends on: the location and geometry of earthquake sources near the site, the recurrence rate of earthquakes of various magnitude on the sources; and the attenuation of ground motions from the sources to the site.

Potential Seismic Sources

The regional geologic and tectonic setting of San Juan Province is characterized by predominantly east-west compression and related volcanism, plutonism, faulting, and sedimentation in fault-bounded basins. Major units or features of significance to an understanding of the geology and tectonics of the region include the subducting Pacific plate, the Andes, the Precordillera, and the Pampean Ranges. From previous works (Ref. 2 and 3) six potencial seismic sources were identified in the region. Figure 1 shows the Tulum Valley area and the location of these seismic sources. For each of them the magnitude of the maximum credible earthquake and its recurrence rate were estimated combining historical seismicity and fault evidences. To this last end several indices were used, such as: observed amount and sense of displacement along faults in the trenches that were excavated during those investigations, scarp height, scarp length, number and height of steams terraces, fault length, etc.. Few of the faults in the province have had sufficient earthquakes to accurately define frecuency-magnitude relationships. Therefore, the regional $\underline{b}$ value for shallow (crustal) seismicity was used for each fault. The $\underline{a}$ values were calculated using the geologically-estimated recurrence values. The data were normalized for time and magnitude intervals. Table 1 shows a summary of Potencial Seismic Sources used in this seismic exposure analysis.

Attenuation of Ground Motion

As only a few strong motion records have been obtained during earthquakes in Argentina, there are insufficient data for regression analysis. Attenuation curves developed by INPRES using the available MMI intensity and seismoscope data for Argentina, were used for shallow (crustal) earthquakes. Figure 2 shows curves of seismic exposure for the Tulum Valley and location of populated areas where the economic losses were determined.

SOIL AND SUBSURFACE CONDITIONS

Tulum Valley is bordered to the east by Sierra Pie de Palo and to the west by Sierra Chica de Zonda, Sierra Villicum and the Tapias and Salado hills. The surface and near-surface rock and sediments of the Valley, can be separated into four distinct zones, as follows: (1) Rock. (2) Alluvial fan deposits of the old course of the San Juan river. (3) Flood plain deposits of the present course of the San Juan river. (4) Transition zone of old fan deposits and flood plain deposits. Both free and constrained aquifers exist in the Valley. Besides, water used in the irrigation of the land percolates only to the impervious near surface layers of fine-grained material where it stays as "perched" ground water. The depth of the free aquifer in the fan area, west of the river, varies from 10 to 100 m below the surface; the perched water table in the rest of the Valley is as shallow as one meter below the surface depending on the time of the year. During a previous study (Ref. 2) ten cross sections of the valley were prepared using available information from water wells, and from 15 new drilled boreholes. The in-situ density was estimated from SPT measurements. Also the shear wave velocities of both the alluvial fan and the flood plain materials were measured by field geophysical tests. During the 1977 earthquake most of the ground failure in the valley was related to liquefaction. Also reports of liquefaction are well documented for the 1894 earthquake (Ref. 5). The potential for the ocurrence of liquefaction in the Valley was computed combining seismic exposure and soil characteristics. The results indicated that the probability of liquefaction ocurring in a 50 year period is generally greater than 50 percent throughout the irrigated portion of the Valley floor.

CHARACTERISTICS OF THE EXISTING CONSTRUCTIONS IN THE AREA

During a specific and detailed survey of the existing constructions in the localities (those with 100 or more dwellings) of the Valley, carried out in 1981 (Ref. 2), more than 83,600 constructions were identified and classified into seven different types according to their earthquake resistance. Types and percentage of dwellings (in brackets) with respect to the total are: (1) Earthquake resistant masonry (57.4 %); (2) Non-earthquake resistant masonry (1.6 %); (3) Reinforced concrete moment resisting frame systems with infilled masonry panels (0.08 %); (4) Shear walls buildings (0.02 %); (5) Earthquake resistant building for industries, warehouses, supermarkets, etc. (0.8 %); (6) Adobe dwellings (39.7 %); (7) Other types (wood, metallic, mixed, etc.) (0.4 %). Since types 3, 4 and 5 jointly represent less than 1 % of the total (0.9 %) and considering their characteristics and response to ground motions they were included as type 1. Therefore, neglecting dwellings of type 7, three principal types of buildings, earthquake resistant masonry, non-earthquake resistant masonry and adobe buildings were considered. Another important feature of the existing constructions in the area is that 95.8 % of them are one story high; 3.9 % two stories high and 0.3 % are three or more stories high. The period of vibration for the majority of the constructions in the Valley was estimated to be less than about 0.2 to 0.3 seconds (Ref. 2).

DAMAGE ASSESSMENT

To estimate the potential damage in existing buildings a direct relationship between the earthquake loading and damage ratio is needed. The earthquake loading will be represented by peak ground acceleration related to Modified Mercalli Intensity. Several authors have proposed different equations to correlate peak ground acceleration and MMI. There is a wide scattering among them and it is known that the relationship is afected by magnitude and epicentral distance. Whether peak ground acceleration is a good parameter to be correlated to Modified Mercalli Intensity or not, will not be discussed here. Any other parameter may be used, but the reliability of each one is still a controversial matter. For this reason acceleration ranges instead of one specific value of acceleration will be correlated with MMI (see Table 2). The relationship between MMI and damage ratio adopted is shown in Figure 3. These curves were proposed by Sauter and Shah (Ref. 1) and they are a kind of "average" of different proposal of several authors. They agree fairly well with the damages observed during the 1977 San Juan earthquake and with historical information of the 1894 and 1944 earthquakes.

PROBABLE POTENTIAL LOSSES

Soil Factors

During the 1977 San Juan earthquake most of the ground failure in the Tulum Valley was related to liquefaction (Ref. 4). Reports of liquefaction are also well documented for the 1894 earthquake (Ref. 5). Three different zones of high intermediate and low liquefaction hazard can be established. In an attempt of considering the liquefaction potential in the probable losses, soil factors are proposed (see Table 3). The values included in the table are based on pure engineering judgment and intent to quantify the fact that the larger the liquefaction potential, the larger the probable potential losses.

Evaluation of Probable Losses

To evaluate the probable potential losses (P.P.L.) the following equation was used:

$$\text{P.P.L.} = \sum_{j} Bj \;.\; EDj \;.\; Cj \quad (j \text{ all types of buildings}) \qquad (1)$$

where

Bj = number of type j buildings
EDj = expected damage for type j buildings
Cj = equivalent cost ratio =

$$= \frac{\text{mean cost per sq. meter of a type j building}}{\text{mean cost per sq. meter of an earthquake resistant masonry building}}$$

The expected damage was obtained as:

$$EDj = \sum_{\text{all } i} P(MMI = i) \;.\; DRj \;.\; S \qquad (2)$$

being:

P(MMI = i) = probability of occurrence of a MMI = i
DRj = damage ratio for a type j building given in figure
S = soil factor from Table 3

The probable potential losses were evaluated for one and twenty five years. Adopted values for Cj are: 1, 0.5 and 0.1 for earthquake resistant masonry, non-earthquake resistant masonry and adobe buildings respectively. The results are shown in Table 4 for each construction type and for each locality. Total P.P.L. are also shown. These P.P.L. were represented by the equivalent number of earthquake resistant masonry dwellings. To evaluate the losses in financial terms these number must be multiplied by the cost of such dwelling.

CONCLUDING REMARKS

The results obtained show that the Tulum Valley area has a high degree of seismic risk. This risk may be quantified as probable potential losses in terms of the cost of typical earthquake resistant masonry dwellings. Assuming a mean cost of 11,000 U$S per dwelling, the probable economic losses would be approximately 3,800,000 U$S per year and 53,400,000 U$S per twenty five years. It should be pointed out, however, that the economic losses mentioned above are only related to buildings. Highways, bridges, irrigation channels, pipelines, etc., were not considered in computing the losses.

ACKNOWLEDGMENTS

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Table 1
Summary of Potential Seismic Source Data
Used for Seismic Exposure Analysis

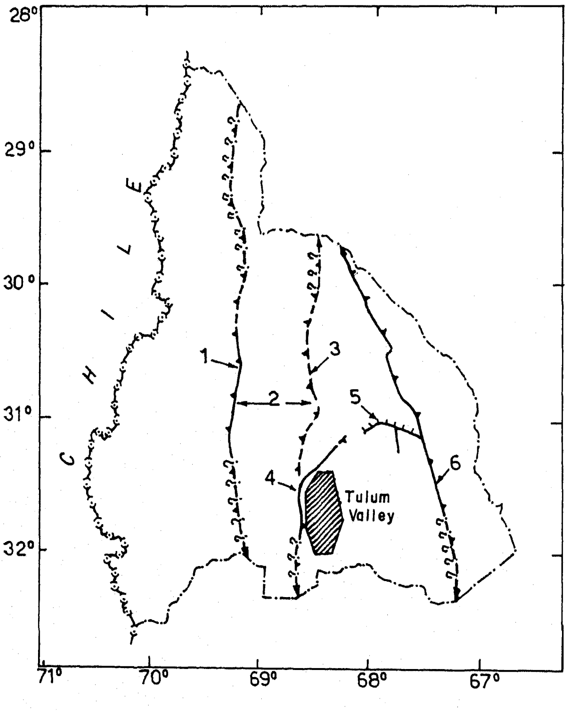
Source		Length (km)	Strike	Dip	Maximum Credible Earthquake	Fault Recurrence (years)
Number	Name					
1	Quebrada de la Caida de Tigre Fault	500	N-S	75°E	8	1,600
2	Precordillera Region Faulting Area	400	N-S	45°W	7-3/4	7,500
3	Frente Norte Fault	250	N-S	45°W	7-3/4	3,200
4	Precordillera Faulting System	250	Note 4	35°E	7-1/2	400
5	Sierra Pie de Palo Fault	60	Note 4	90°	7-3/4	4,000
6	Sierra Valle Fertil'Fault	400	N70°W	45°E	7-3/4	15,000
7	Benioff Zone	-	-	Horizontal	7-1/2	15,500

Table 2
PGA Ranges vs MM Intensities

MMI	PGA(%g)
V	5
VI	5-10
VII	10-20
VIII	20-35
IX	35-50
X	50

Table 3
Soil Factors Adopted for Liquefaction Hazard

Liquefaction Hazard	High	Intermediate	Low
Soil Factor	1,2	1,1	1,0



Potential Seismic Sources

1.- Quebrada de la Caída del Tigre Fault
2.- Precordillera Region Faulting Area
3.- Frente Norte Fault
4.- Precordillera Faulting System
5.- Sierra Pie de Palo Fault
6.- Sierra Valle Fértil Fault

Figure 1: Potential Seismic Sources in San Juan Province

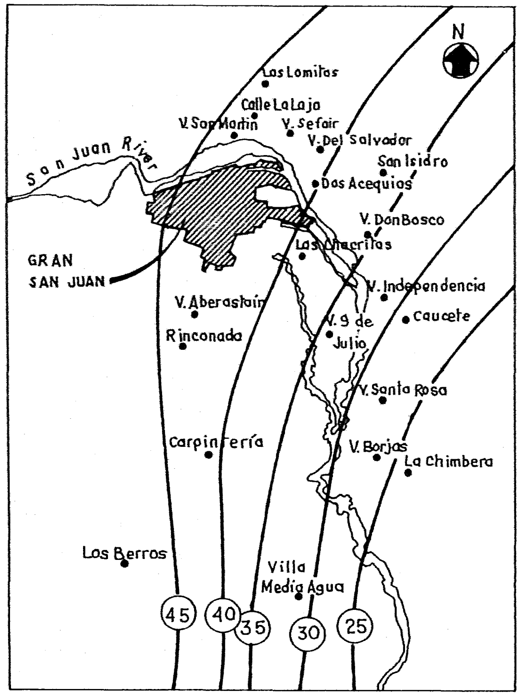


FIGURE 2 Contour of PGA (%) having a 10% probability of exceedance in 25 years

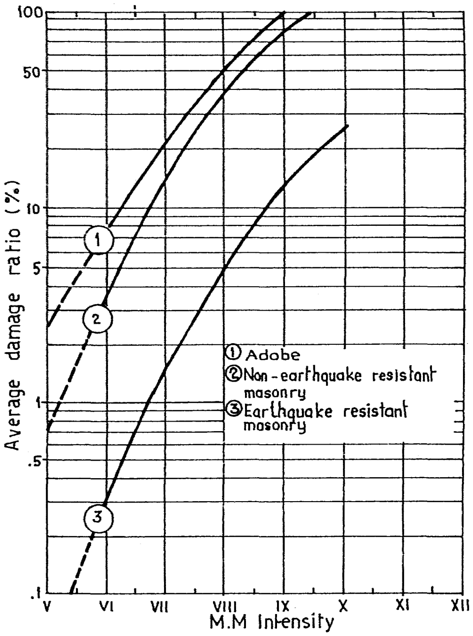


FIGURE 3 Damage ratio vs M.M. Intensity

Table 4 - Probable Potential Losses

County	Locality	Masonry Buildings						Adobe Buildings			P. P. L.	
		Earthquake Resistant			Non-Earthquake Resistant							
		Number of Buildings	E. D. % 1 year	E. D. % 25 years	Number of Buildings	E. D. % 1 year	E. D. % 25 years	Number of Buildings	E. D. % 1 year	E. D. % 25 years	1 year	25 years
Albardon	Va. San Martin	242	0.4	6.6	2	3.2	45.0	164	6.3	63.9	2.0	26.9
	Calle La Laja	189	0.4	6.4	2	3.1	44.0	345	6.2	62.6	2.9	34.1
	Las Lomitas	14	0.4	6.3	2	3.0	43.6	138	6.1	62.2	0.9	9.9
Angaco	Sefair-Talacasto	42	0.4	6.3	-	-	-	142	6.2	62.7	1.1	11.6
	Va. El Salvador	293	0.4	6.3	1	3.1	43.8	116	6.2	62.5	1.9	25.9
Capital	Gran San Juan 1	3.835	0.3	5.8	-	-	-	81	5.5	55.8	12.0	226.9
	Gran San Juan 2	4.596	0.3	5.8	47	2.8	39.5	931	5.5	55.8	19.6	327.8
	Gran San Juan 3	5.929	0.3	5.8	101	2.8	39.5	2.837	5.5	55.8	34.8	522.1
	Gran San Juan 4	4.188	0.3	5.8	26	2.8	39.5	2.036	5.5	55.8	24.1	361.6
	Gran San Juan 5	3.560	0.3	5.8	170	2.8	39.5	2.322	5.5	55.8	25.8	369.6
Caucete	Ciudad de Caucete	2.187	0.2	3.4	-	-	-	1.507	5.0	41.7	11.9	137.2
	Va. Independencia	26	0.3	4.1	-	-	-	157	5.3	46.7	0.9	8.4
Chimbas	Gran San Juan 1	1.764	0.3	5.8	146	2.8	39.5	1.707	5.5	55.8	16.7	226.4
	Gran San Juan 2	1.734	0.3	5.8	65	2.8	39.5	2.101	5.5	55.8	17.7	230.6
	Gran San Juan 3	124	0.3	5.8	6	2.8	39.5	428	5.5	55.8	2.8	32.3
9 de Julio	Las Chacritas	48	0.4	6.2	-	-	-	226	6.1	61.6	1.6	16.9
	Va. 9 de Julio	258	0.3	4.7	-	-	-	112	5.5	50.5	1.4	17.8
Pocito	Gran San Juan	191	0.3	5.8	-	-	-	854	5.5	55.8	5.3	58.7
	Va. Aberastain	576	0.4	6.7	-	-	-	852	6.0	62.5	7.4	91.8
	La Rinconada	115	0.4	6.7	2	3.1	-	177	6.0	62.5	1.6	19.2
	Carpinteria	82	0.3	5.4	-	-	-	137	5.4	52.5	1.0	11.6
Rawson	Gran San Juan	8.530	0.3	5.8	268	2.8	39.5	6.725	5.5	55.8	66.3	922.9
Rivadavia	Gran San Juan	2.063	0.3	5.8	118	2.8	39.5	1.605	5.5	55.8	16.7	232.5
	Gran San Juan	1.290	0.3	5.8	48	2.8	39.5	1.490	5.5	55.8	12.7	167.4
	Gran San Juan	1.727	0.3	5.8	260	2.8	39.5	1.129	5.5	55.8	15.0	214.5
San Martin	Dos Acequias	42	0.4	6.4	-	-	-	102	6.2	62.7	0.8	9.1
	San Isidro	29	0.3	5.9	-	-	-	107	5.9	59.4	0.7	8.1
	Don Bosco	190	0.3	5.3	-	-	-	109	5.7	55.5	1.2	16.1
Santa Lucia	Gran San Juan	3.578	0.3	5.8	91	2.8	39.5	2.639	5.5	55.8	26.8	375.5
	Alto de Sierra	181	0.4	6.6	-	-	-	547	6.3	64.2	4.2	47.1
Sarmiento	Cieneguita	56	0.3	5.1	-	-	-	54	5.0	50.7	0.4	5.6
	Los Berros	171	0.3	5.1	-	-	-	295	5.0	50.7	2.0	23.7
	Va. Gral. Sarmiento	347	0.2	3.7	-	-	-	367	5.0	40.1	2.5	27.6
25 de Mayo	Va. Santa Rosa	193	0.2	2.9	2	2. 0	23.4	194	4.7	37.1	1.3	13.0
	Va. Borjas	262	0.2	2.7	6	1. 9	21.6	171	4.6	34.5	1.4	13.6
	La Chimbera	125	0.2	2.2	1	1. 7	18.4	301	4.4	30.5	1.6	12.0
Total		48.777			1.364			33.255			347.1	4851.5