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P. Acevedo
University of Chile, Chile

J. Monge
University of Chile, Chile

M. Astroza
University of Chile, Chile

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Professor of Civil Engineering, University of Chile, Chile

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SYNOPSIS: The geotechnical units forming the foundation soil of Valparaíso city and constituting seven zones that exhibit different stratigraphic sequences, are characterized. In addition, the evolution of the artificial backfillings located in the seaport is reported. The damages causes by Chile Earthquake of March 3, 1985 allow to establish for each zone the MSK intensities, which are varying between 7 1/2 and 8 1/2 in the flat-ground sector of Valparaiso, and between 7 1/4 and 7 1/2 in the hills. The major intensity in the flat sector is observed in areas whose artificial backfillings are exhibiting greater thickness and less consistency or less compacity.

INTRODUCTION

The Chile earthquake of March 3 (1985, with a magnitude Ms = 7.8) belongs to the family of destructive earthquakes that occur in the same epicentral area with a remarkable periodicity of 82 +/- 6 years. About six millions inhabitants live in the area affected by the earthquake, totaling half of the country's population. The earthquake produced a considerable damage in fragile constructions, such as adobe and unreinforced masonry dwellings, located in the region bounded by the city of Illapel, on the North, the city of Cauquenes, on the South, the coast of the Pacific Ocean, on the West, and the foothills of the Andes, on the East, Fig.1.

Valparaiso city's high seismic hazard has motivated the present work centered on the analysis of soil mechanics information and of seismic information gathered in pits and/or boreholes, as well as on their relationship with the intensity observed in the divers geotechnical units.

The basic information for undertaking this study is formed by the report of damages and their verification in the field, the MSK scale available for different types of construction and the characterisation of foundation soil.

GEOLOGY AND GEOTECHNICAL UNITS

Valparaiso is exhibiting a typical geomorphology of a regression coast. The flat sector thereof is forming a beach surrounded by hills of metamorphic rock folded and/or intruded by some granodioritic pluton that would have produced an extense aureole of transition gneiss
Valparaiso soil is formed by some of the strata, locally ordered in different sequences, described below in keeping with their relative rigidity:

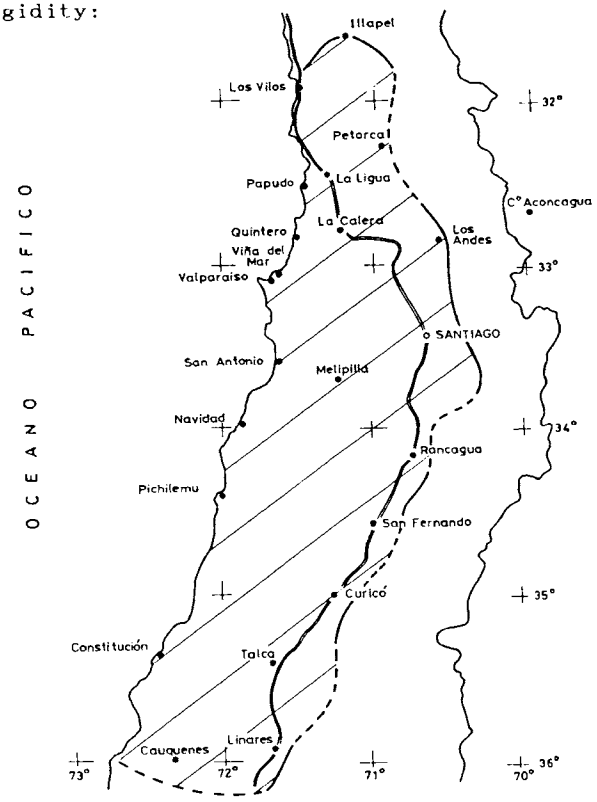

Fig. 1. Area of Damage, Chile Earthquake of March 3, 1985.

E1: Fundamental Rock, Sound and/or Partially Fractured.

Depth thereof varies between 3 and 30 meters in the high sector, and between 6 and 50 meters in the flat sector. Largest depths are located in the axe of ravines and in the vicinity of the today coast; smaller depths are located at the foot of the cliff and at the edges of the ravines.

E2: Fundamental Rock, Partially Weathered.

Depth is varying between 0.15 and 0.5 meter. Largest thicknesses are located in the zones where the rock is more superficial.

E3: Weathered Rock.

This corresponds to residual granitic soil (maicillo in Spanish), or to rock weathered in situ. In general it is located in the hills, and thicknesses thereof vary between 2 and 13 meters; largest thicknesses are associated with zones of reduced slope.

E4: Alluvial and Colluvial Sediments (Natural Backfillings).

These sediments are made of coarse to fine sands with silty and clayish fines, gravels and, locally, rocky blocks. Compacity is loose at the surface, and is medium or very dense with increasing depth. This stratum surrounds the hills, starting from contour elevation + 20 where the greatest depth is attained, down to the original coastal line, reaching there 2 to 4 meter thickness.

E5: Estuarial Marine Sediments.

This stratum has been formed through sea abrasive action on the rocky massifs and has been depositing in shallow or underground waters in the form of coarse, medium and fine sands, with diverse percentages of silts. Compacity ranges from dense to very dense.

E6: Sands of Old Beaches.

This stratum extends from Avenida Colón, calle Condell and calle Serrano to the present coast. It is made of fine to coarse sands with varying percentages of gravels. Thickness range from 10 to 23 meters between the original coast and the present one, and from 18 to 28 meters in the remaining portion of the area where this stratum has been detected.

E7: Sand of Modern Beaches.

This sand has coarse to fine particles with different percentages of silts with a reduced amount of gravels. Compacity varies from loose to medium. Maximum thicknesses are to be found in the present coast and they are reaching up to 21 meters; minimum thicknesses are detected at 5-meter depth at the foot of the Cerro Placeres hill.

E8: Artificial Backfilling.

This unit has been produced by a series of partial back-fillings, Figure 2. It has varying composition that includes chiefly sands with demolition rubbish, fragments of brick, concrete slabs, rocky blocks, gravel and cobble stones. Major thicknesses are located along the present coastal line (11 and 12 meters) while minor thicknesses are to be found in the vicinity of contour elevation +20.

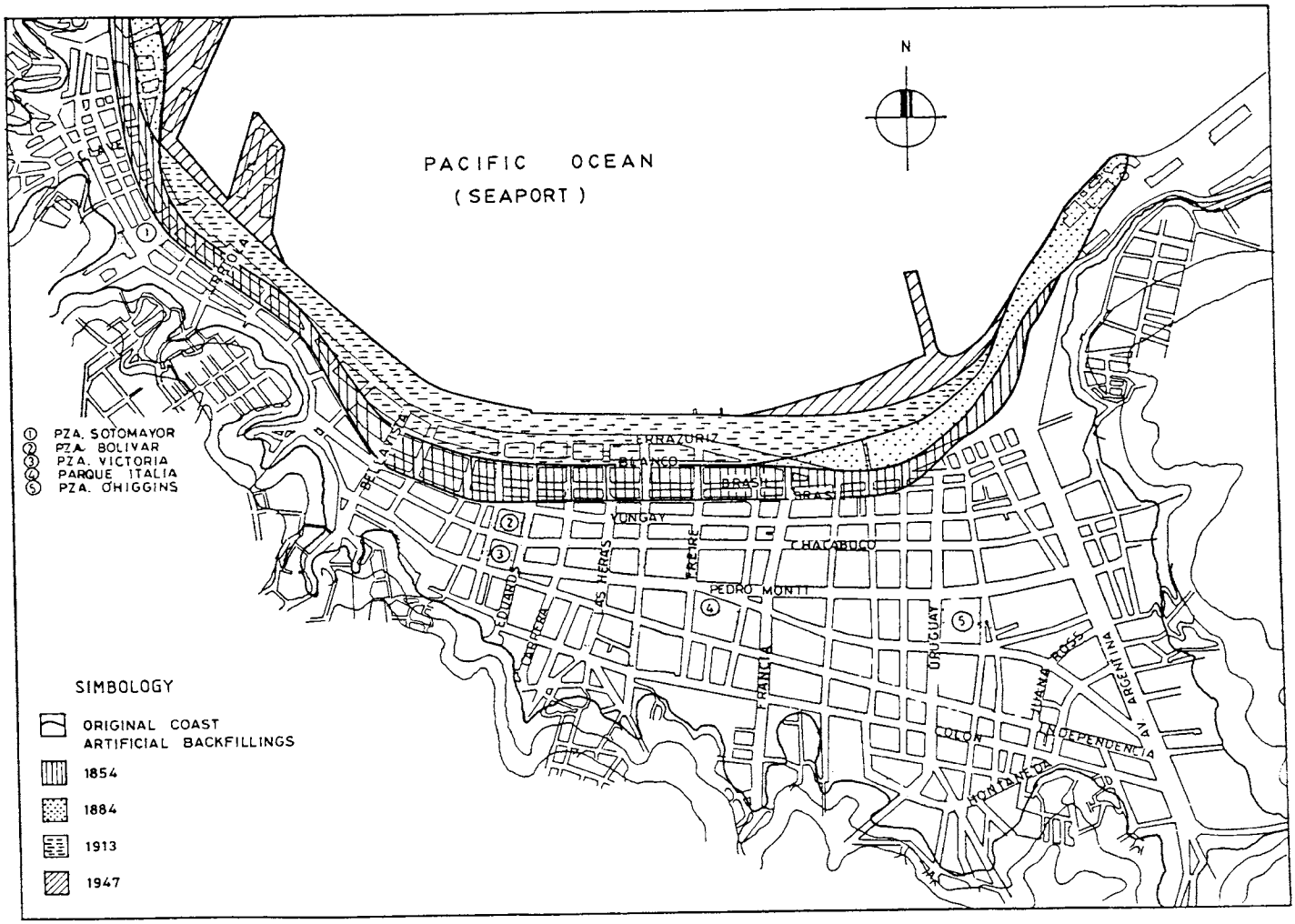

Fig. 2 Evolution of Artificial Backfillings Flat-ground Sector of Valparaiso.

The foregoing background data allow to classify foundation soils into 7 zones whose characteristics are detailed in Table I below in accordance with an ordering that follows the increasing depth of the strata composing these soils, Figures 3 and 4.

TABLE I. Zoning of Valparaiso City Soils

ZONE:	STRATA SEQUENCES
Zone I:	E8/E7/E6/E5/E1
Zone II:	E8/E4/E7/E6/E5/E1
Zone III:	E8/E4/E5/E1
Zone IV :	E8/E1 or E2
Zone V :	E4/E5/E2/E1
Zone VI:	E8/E5/E4/E3/E2/E1
Zone VII:	E3/E2/E1

DETERMINATION OF THE INTENSITY DEGREE.

The methodology used to compute the intensity degree considers the study of reports on damaged structures, identifying cases of one story adobe houses, which were assimilated to Type A from the MSK Scale, and those of one story unreinforced brick masonry houses, assimilated to Type B. When these types of dwellings were not present, Type C-reinforced brick masonry houses, or a Type (TA) defined with one and two stories houses of wooden braced frame infilled with adobe blocks, were considered.

The main cities were divided in sectors of approximately one square kilometer, each of them located on the same unit of soil Table II gives the number of sectors and structures considered in the area affected by the earthquake.

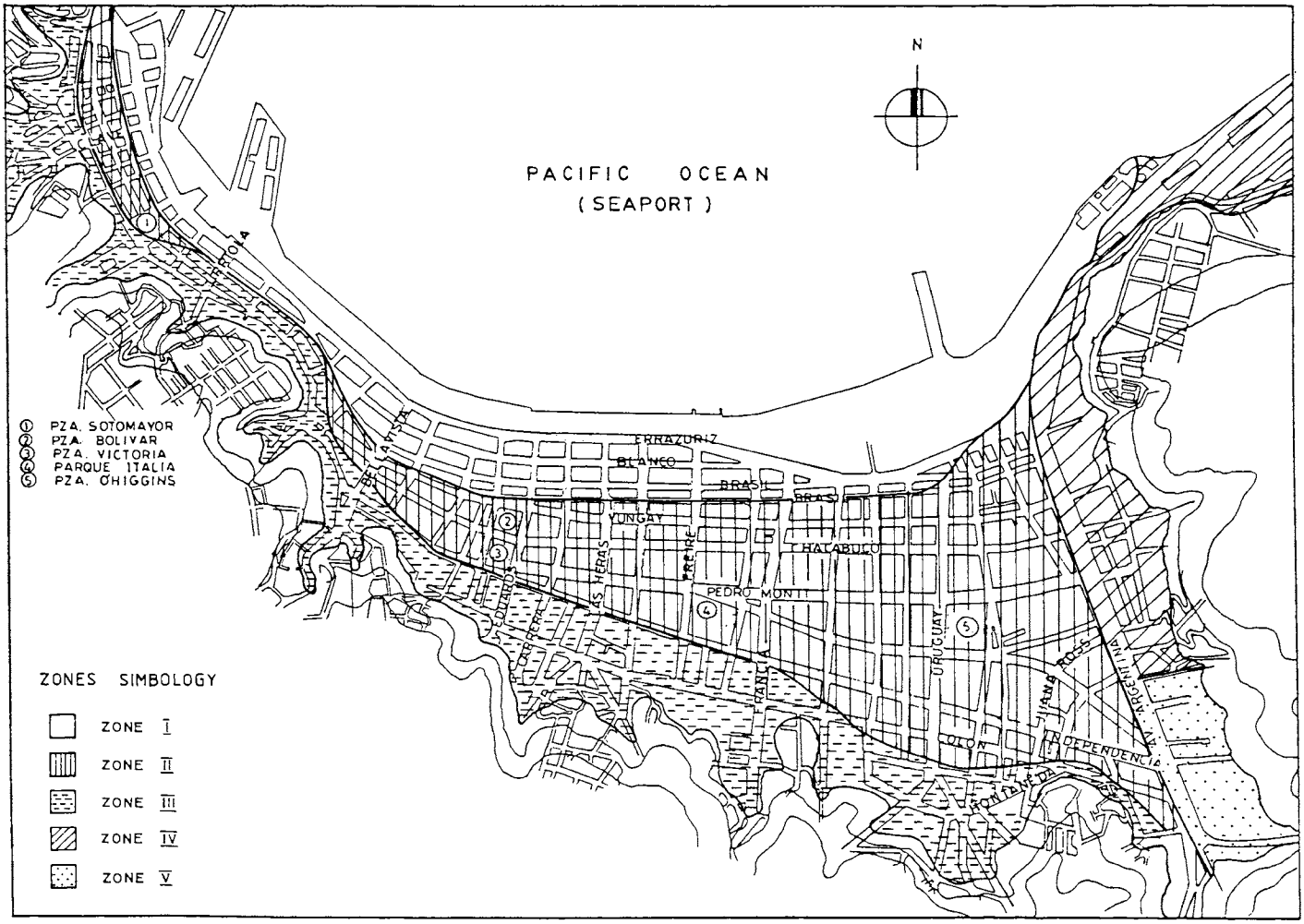

Fig. 3 Zoning of the Foundation Soil in Valparaiso Flat-Ground Sector.

TABLE II. Sectors - Structural Types

Location and Sector		Structural Types			
		A	AT	B	C
City of Santiago	288	16,538	--	21,827	8,390
City of Valaparaiso	25	--	2,582	257	--
City of San Antonio y Llolleo	22	--	--	909	983
4ª, 5ª, 6ª, 7ª and Metrop. Regions	487	25,373	2,883	1,075	291
Total	822	42,209	5,465	24,069	9,664

The degree of damage was assigned from the description given in each report using six grades as follows:

Grade 0: No Damage.

Grade 1: Small Damage.

Grade 2: Moderate Damage.

Grade 3: Severe Damage.

Grade 4: Partial Destruction.

Grade 5: Total Collapse of Buildings.

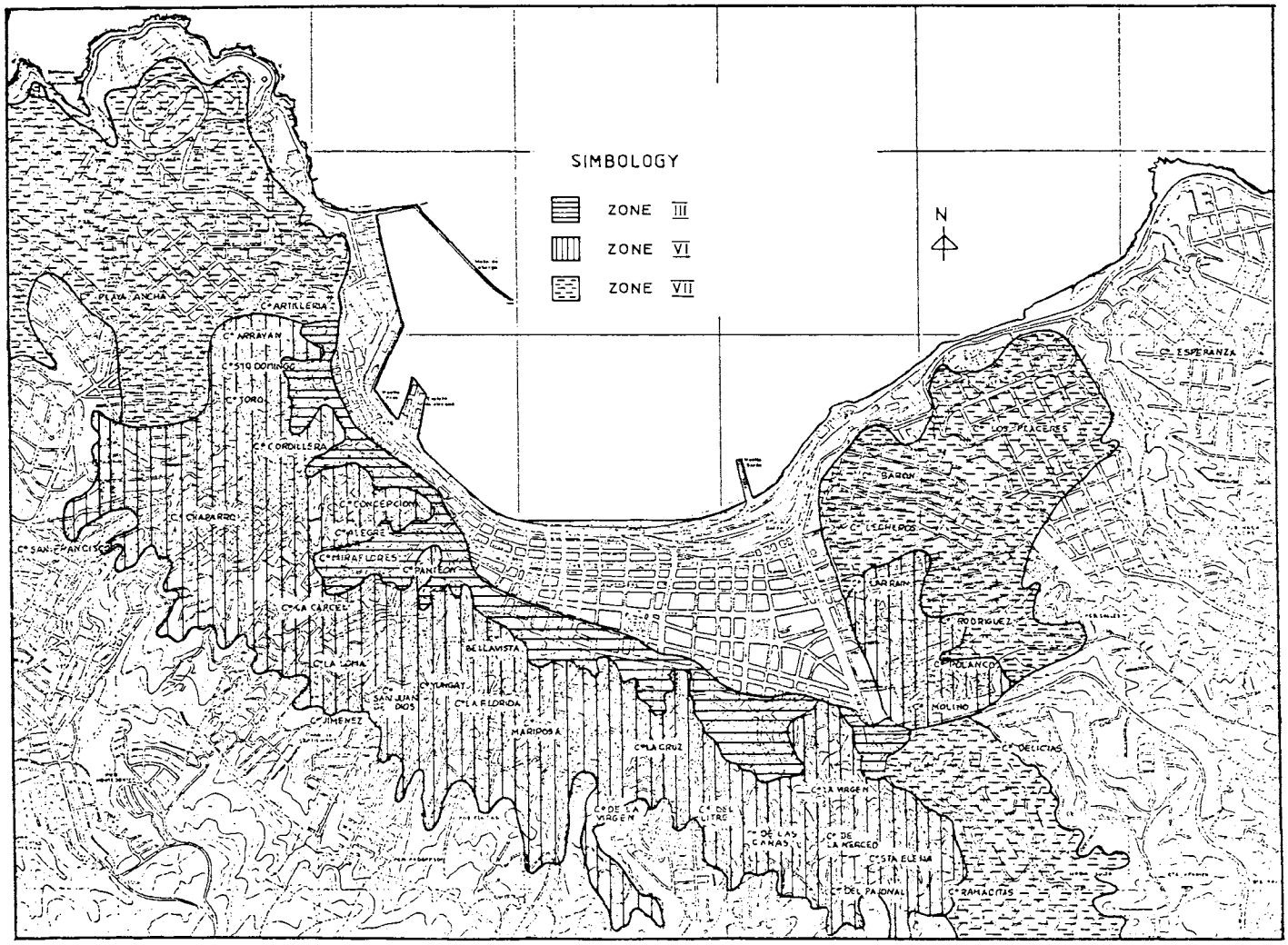

Fig. 4 Zoning of Foundation Soil in the High Sector of Valparaiso City.

The relationship between the degree of damage of the basic types of structures and the intensity degree is shown in Table III, which corresponds to the description of the MSK scale, defining in percentage the number of houses damaged. The percentages in brackets are estimated by Kárník, Schenkova and Schenk completing the original MSK scale, in order to achieve 100% for each degree and structural type.

The classification used by the MSK Scale makes possible a graphic representation for each intensity degree over 5 as a curve of cumulative percentages of damaged houses versus the grade of damage. In this representation the statistical behavior of each sample (sector) can be drawn and the intensity degree is obtained by an interpolation process.

TABLE III. Percentages of Damage for Individual Degrees of the MSK Scale.

MSK 64 Intensity	Type of Structure		
	A	B	C
5	5% grade 1 95% grade 0	100% grade 0	100% grade 0
6	5% grade 2 50% grade 1 45% grade 0	5% grade 1 95% grade 0	100% grade 0
7	5% grade 4 50% grade 3 35% grade 2 10% grade 1	50% grade 2 35% grade 1 15% grade 0	50% grade 1 50% grade 0
8	5% grade 5 50% grade 4 35% grade 3 10% grade 2	5% grade 4 50% grade 3 35% grade 2 10% grade 1	5% grade 3 50% grade 2 35% grade 1 10% grade 0
9	50% grade 5 35% grade 4 15% grade 3	5% grade 5 50% grade 4 35% grade 3 10% grade 2	5% grade 4 50% grade 3 35% grade 2 10% grade 1
10	75% grade 5 25% grade 4	50% grade 5 35% grade 4 15% grade 3	5% grade 5 50% grade 4 35% grade 3 10% grade 2
11	100% grade 5	75% grade 5 25% grade 4	50% grade 5 50% grade 4

SEISMIC INTENSITIES IN THE CITY OF VALPARAISO.

Seismic intensities are computed in accordance with the procedure described in Reference 3, taking into account the damages causes in the structures Type TA, which are prevailing in the zone. The classification of damages detailed in Table IV is adopted for this type of dwellings.

Seismic intensity is determined by using the standard curves of Type A structures of the MSK Scale, which does not consider structures of Type TA, and this fact obliged to carry out a certain correction. This correction was obtained by comparing the intensities regarding adobe and regarding timber braced frame infilled with adobe in this study as well as in the other ones on the effects of March 3, 1985 earthquake. The conclusion was thus reached that for intensities ranging from 6 1/2 to 8 it suffices to add 1/4 of degree to the value obtained for structures Type TA, in order to assimilate them to adobe dwellings.

Table IV. Grades of Damage for 1 and 2 Story Structure Type TA.

Grade 1: Cracks along vertical and diagonal members of timer frames.
Grade 2: Falling of Plaster fragments, thus uncovering adobe brick.
Grade 3: Falling of a portion of adobe bricks that are filling timber frames.
Grade 4: Falling of an adobe partition-wall with timber frame.
Grade 5: Falling of more than one adobe partition-wall with timber frame.

In the high sector of Valparaiso 1-story structures were considered. On the other hand, in the flat sector of the city, structures of two stories were added increasing the size of the sample.

Figure 5 shows the intensity degrees in the sectors of Valparaiso city subdivision. This figure is clearly illustrating a special D-shaped sector formed by the perimeter comprising the streets of Victoria, Hontaneda, Rancagua and Uruguay, because this D-sector represents a case of major destruction that has to be taken into account in order to avoid altering the results of adjacent sectors.

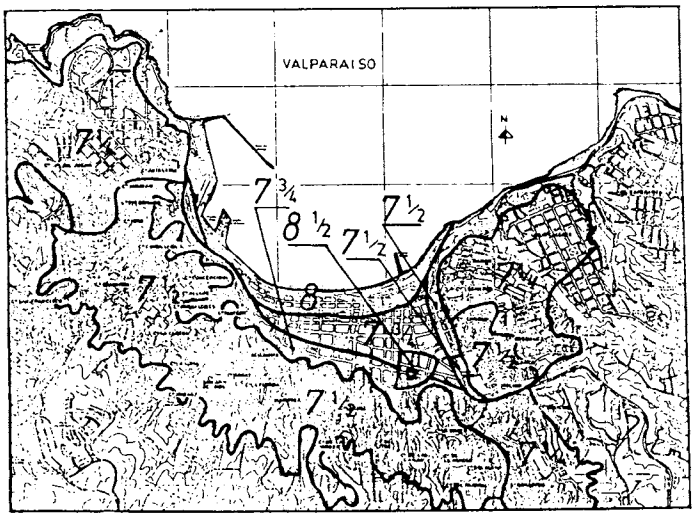

Fig. 5 Zoning of Valparaiso City Soils.

ANALYSIS AND COMMENTS

The comparison of the intensity degree obtained in the different sectors of Valparaiso city allows to observed that intensity degree increase in possibly due to the larger thicknesses and to the lesser consistency or lesser compacity of the stratum formed by artificial backfillings (E8), as in occurring in types I, II and III soils. The analysis of the behavior of types IV, V and VII soils allows to observe that the more superficial the fundamental rock (E1), the lesser the earthquake intensity. As a rule, seismic intensity is decreasing in all types of soil when their compacity or consistency in increasing.

On the other hand the system of self-build housing as well as the presence of slopes and ravines, imposes variations in intensity degree, so that the same is increased by 1/4 of degree. This fact could be observed in the high sector of Valparaiso.

In the above mentioned D-sector, that was separately analyzed for the reasons already stated, an intensity of 8 1/2 was obtained. This zone comprising foundation soils II and III, has been particularly affected and this might be due to some local effect of soils interphase at this location. The fundamental rock (E1) in this zone is situated at a greater depth than in the remaining sectors of Valparaiso flat area, and the stratum made of artificial backfillings (E8) is having a compaction or consistency ranging from very loose (soft) to medium.

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