Soil liquefaction in Peru

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ABSTRACT: A brief review of soil liquefaction and maximum seismic intensities that occurred in Peru since the XVI th century is presented. Two cases of recent earthquakes that induced soil liquefaction will be described: the May 31, 1970 Chimbote event on the peruvian coast and the May 29, 1990 and April 4, 1991 earthquakes in the northern peruvian jungle.

INTRODUCTION

The main purpose of this paper is to present the information available on the occurrence of soil liquefaction in Peru, a southamerican country located on the pacific coast, one of the most active seismic regions in the world. Seismic activity in this region is mainly caused by the subduction of the Nazca Plate beneath the South American Plate, but there is also continental fault activity.

Several researchers have compiled historical information about the most important seismic events that occurred in Peru from the XVI th century to the present time (Silgado, 1978). In this presentation two cases of relatively recent earthquakes that induced soil liquefaction will be presented: the May 31, 1970 Chimbote event, on the peruvian coast and the May 29, 1990 and April 4, 1991 earthquakes in the Alto Mayo region in the Peruvian Orient.

OBSERVED SEISMIC INTENSITIES AND SOIL LIQUEFACTION

A map of maximum seismic intensities observed (MM) in Peru was presented by Alva Hurtado et al (1984). The map was based upon thirty isoseismal maps of recent earthquakes and point intensities of historical earthquakes. The map represents the level of damage irrespective of the cause: ground shaking, liquefaction, landslides triggered by earthquakes or others. This map was prepared as part of a regional project supported by CERESIS. (Regional Center for Seismology in South America).

The map indicates high seismic activity on the peruvian coast due to the subduction of the Nazca plate underneath the South American Plate; moderate seismic activity can be noted in the Subandean Zone located in the northeastern jungle, east of the Andes mountain. Intensities up to X were observed on the coast of Peru in large zones whereas in the subandean zone the attenuation is higher with high intensities were noted in specific sites. Figure Nº 1 presents the Distribution of Maximum Seismic Intensities Observed in Peru.

A review of historical information of soil liquefaction in Peru was undertaken by Alva Hurtado (1983). Evidence of liquefaction such as developing mud and sand boils, violent expulsion of water from the ground, presence of intense craking and differential subsidence due to seismic events was taking into consideration. A map of Peru showing differences between real and probable liquefaction areas found in the literature was compiled and is presented in Figure Nº 2.

Twenty seven cases of soil liquefaction in Peru were determined. The phenomena occurred on the coast, the highlands and the northen jungle. On the

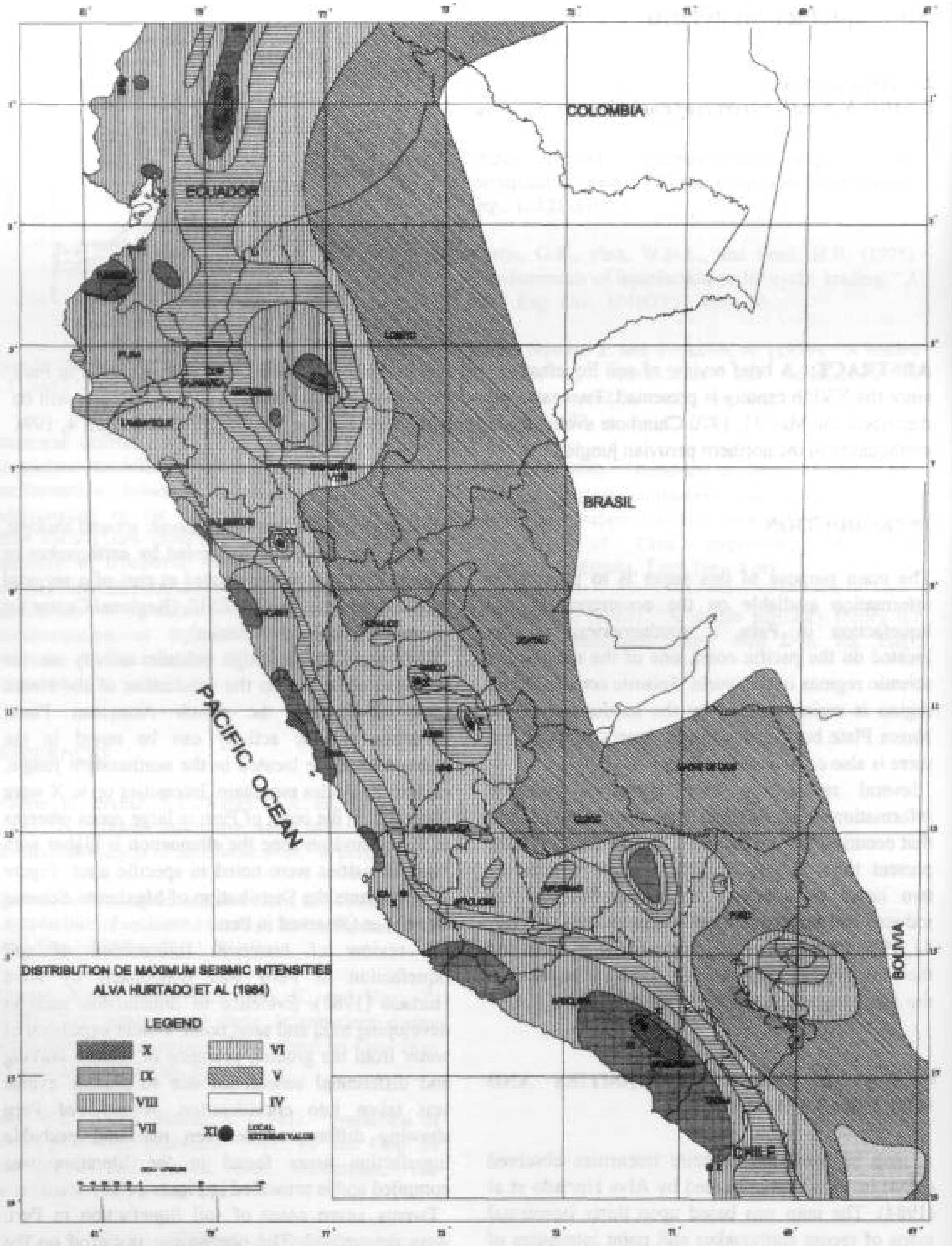


FIGURE N°1 DISTRIBUTION OF MAXIMUM SEISMIC INTENSITIES OBSERVED IN PERU

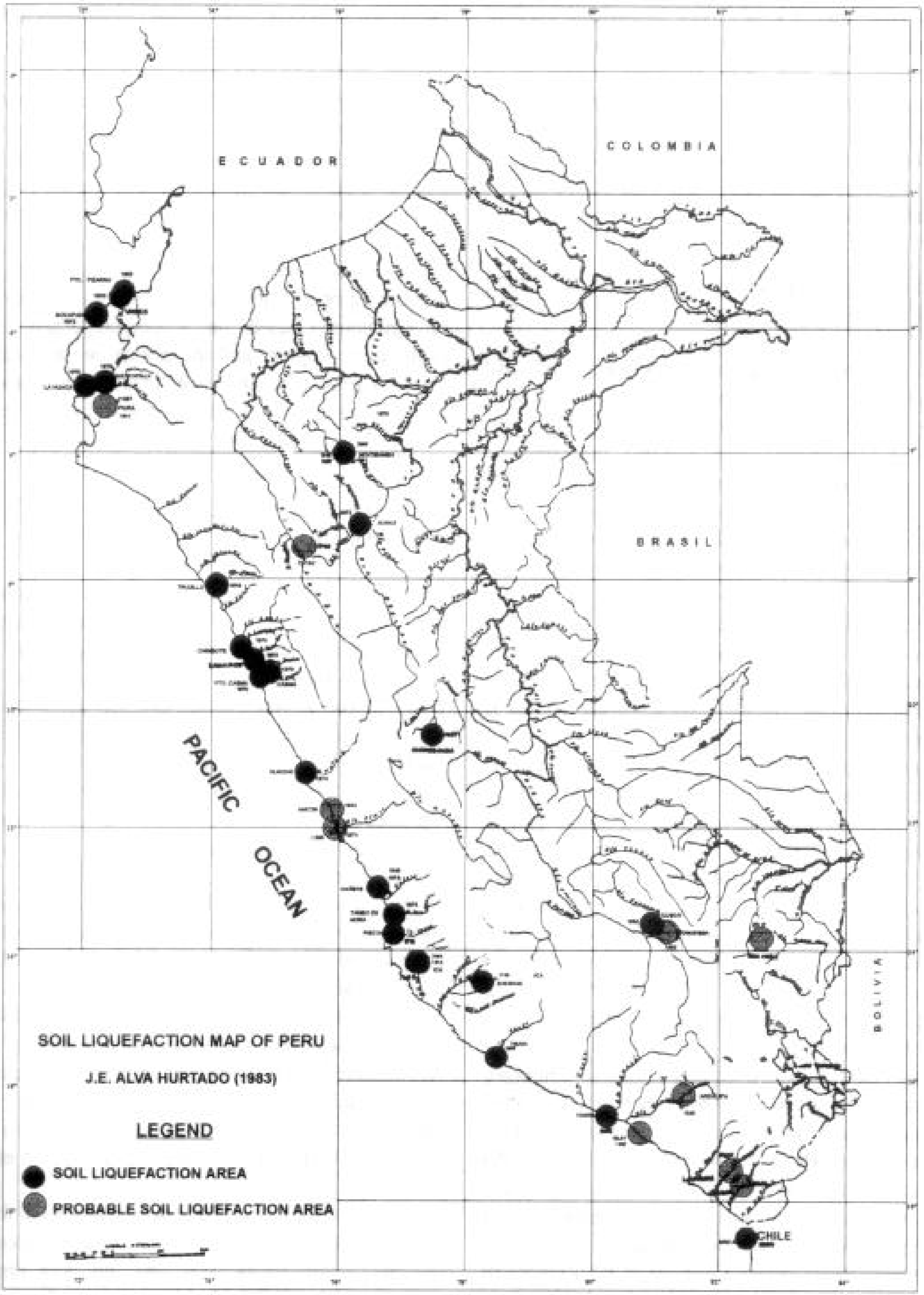


FIGURE N° 2 SOIL LIQUEFACTION AREAS IN PERU coast soil liquefaction is more generalized because of higher seismicity and the existance of more population in this part of Peru. There is a correspondance between higher intensities and soil liquefaction occurrance in Peru. Examples of earthquakes that produced soil liquefaction in the desertic coast and the jungle and their effects will be described in this paper.

SOIL LIQUEFACTION CAUSED BY 1970 EARTHQUAKE

One of the best documented cases of soil liquefaction in Peru is the one relevant to the May 31, 1970 earthquake in Chimbote. The city is located about 400 kilometers north of Lima, the capital of Peru. On May 31, 1970 an earthquake of magnitude Ms=7.8 and focal depth of 45 kilometers occurred 50 km offshore west of Chimbote. A strong motion record of the earthquake was obtained in Lima, with a maximum horizontal acceleration of 0.11 g. No record was obtained at Chimbote. Maximum intensity of IX in the Modified Mercalli Scale was observed. A brief summary of liquefaction effects in Chimbote during the May 31, 1970 earthquake is presented.

Ericksen et al (1970) and Plafker et al (1971) indicated that in Casma, Puerto Casma and near the coast of Chimbote, lateral spreading of the ground caused by liquefaction of deltaic and beach deposits was produced. Cracks that affected structures were observed on the ground. Chimbote's central zone (Casco Urbano) was evidently an area of soil liquefaction and of differential compaction. In Chimbote, Casma and along the Panamerican Highway ground subsidence due to liquefaction, was noticed on the surface.

Cluff (1971) reported ground failure in Chimbote because of saturated and loose beach deposits. Sand volcanoes and water ejection were observed in several areas where the water level was near the surface. Berg and Husid (1973) verified the occurrence of soil liquefaction in the foundation of the Mundo Mejor school in Chimbote.

Carrillo (1970) reported settlement of accesses to almost all of the bridges in the Panamerican Highway and subsidence of the Chimbote Port Terminal. He also presented evidence of saturated sand liquefaction at Elías Aguirre street in Chimbote.

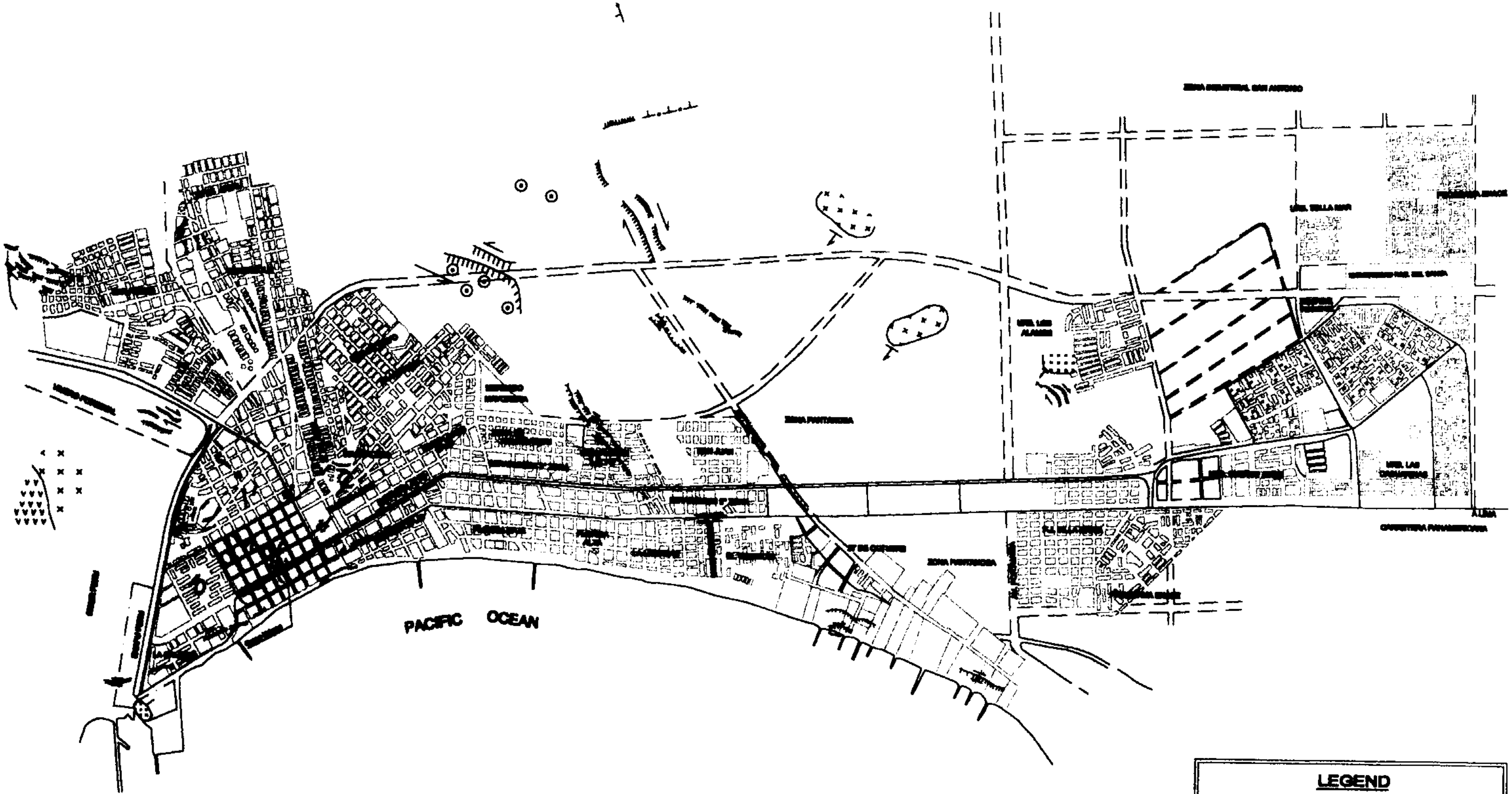
Morimoto et al (1971) described soil liquefaction in Chimbote and presented a distribution map of ground cracks and sand volcanoes (Figure Nº 3). In the backswamps and lowlands in alluvial deposit, general liquefaction was developed with cracks due to differential compaction of soil deposits. In alluvial deposits, subsurface liquefaction developed, generating cracks with sand volcanoes and damage to wells.

Alva-Hurtado and Parra (1997) presented an assessment of soil liquefaction potential for the city of Chimbote, based on a comprehensive soil exploration program and the evaluation method of TC-4. A good comparison of liquefaction potential sites with the soil effects produced by the 1970 earthquake was obtained.

GROUND EFFECTS CAUSED BY 1990 AND 1991 EARTHQUAKES

On May 29, 1990 and April 4, 1991, two moderate earthquakes occurred in the northeastern region of Peru. Despite their relatively low magnitudes, the severity of the damage was high because of the existing type of construction and soil conditions in the populated areas. The region is located in North Eastern Peru, with high precipitation and temperature. Sedimentary rocks from the Jurassic to Cretaceous Periods are found in the nearby mountains and Quaternary materials in the Alto Mayo river valley. Quaternary deposits are composed of alluvial, colluvial, fluvial and residual soils. Moyobamba and Rioja are the most important cities in the area. The region is crossed by the Mayo river, whose banks are composed of liquefiable sand deposits. The following earthquake ground effects have been reported: soil liquefaction, instability and soil erosion in the slopes, differential settlements, soil amplification and landslides within the epicentral area. The soil liquefaction effects in Moyobamba city are described. (Alva-Hurtado et al, 1992).

The type of faulting in the area corresponds to folds and high angle thrust faults that form imbricated systems. These faults have less dip with depth; producing a thrust and fold belt structure. Several of these faults have visible traces and evidence of recent activity. Valley scarps can be seen to the west of the Alto Mayo, as well as longitudinal valleys and



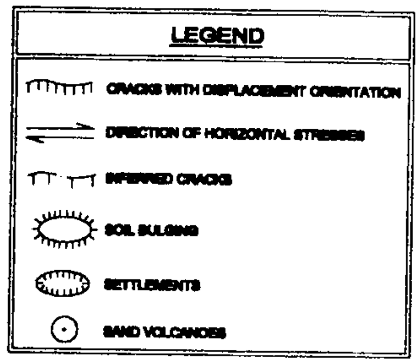


FIGURE N°3 SOIL LIQUEFACTION EFFECTS IN CHIMBOTE BY MAY 31,1970 EARTHQUAKE

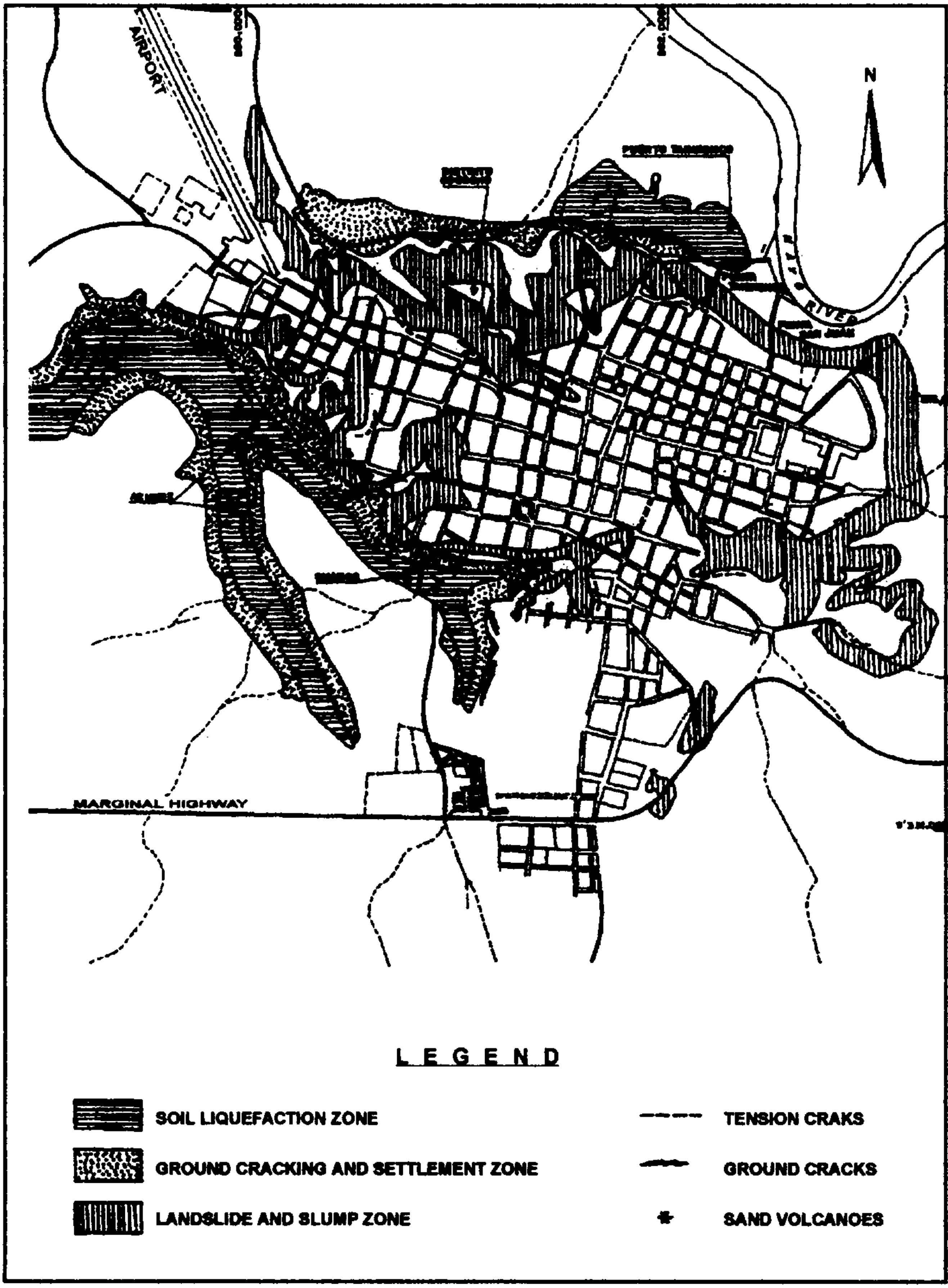


FIGURE Nº 4 GROUND EFFECTS IN MOYOBAMBA CITY BY MAY 29, 1990 AND APRIL 4, 1991 EARTHQUAKES

displaced morphological units, typical of active transcurrent faults. Also, to the north and south of Moyobamba, rectilinear scarps can be seen that could correspond to active normal faults (Martínez and Machare, 1991).

The city of Moyobamba was originally built on a stable plateau constituted by residual soils. The slopes around the city have erosion problems. The lowlands in Moyobamba, such as Tahuishco, Shango and Azungue have soft quaternary soils. The geotechnical types of damage are briefly reported, such as: ground cracking, soil liquefaction, soil amplification and landslides.

Ground Cracking.- Tension cracks were observed in 1) the crest of the slopes of the Moyobamba plateau, associated with soil liquefaction and lateral spreading, 2) the highways, as tension zones that could developed future landslides and slumps, 3) the soft soils in the Mayo river banks.

Soil Liquefaction.- Soil liquefaction occurred in Port of Tahuishco in Moyobamba. Lateral spreading developed in the school of Tahuishco in 1991 with cracks 10 cm wide and 50 cm deep. One classroom floor was destroyed. In 1990 the phenomenom did not reach the school building, but did occur in the school yard; sand volcanoes also appeared in the school yard. During both earthquakes, segments of the highway between Moyobamba and Tahuishco were damaged.

In Azunge, located in the lowlands of Moyobamba, ground cracks and lateral spreading developed. Cracks 100 m long and 40 cm wide with depths of 1 m were reported. Most of the houses on the slope collapsed. The sewage pumping station and sewage disposal pipes failed. All tapial houses and some masonry houses on soft ground collapsed. In Shango, tapial houses collapsed. Cracks 80 m long and 20 cm scarps were observed. On Miraflores street, the cracks were 30 m long and 30 cm deep. During the 1990 earthquake soil liquefaction was reported in El Chorro and Molino Valencia in Rioja, also in Segunda Jerusalen-Azunguillo, Negro river and La Conquista.

Figure Nº 4 presents the earthquake ground effects in the city of Moyobamba. The subsoil in the lower parts of the city, such as Tahuishco, Azungue and Shango consists of fine sands and silty sands with low relative densities and high water level. The soil in the slopes is constituted mainly by clayey and silty sands with medium densities and relatively low water table, whereas the ground in the elevated part of the city (plateau) consists of clays and clayey sands of medium to low bearing capacities and deep water table. Seismic intensities in the lower part where two degrees higher than in the elevated part of the city of Moyobamba.

CONCLUSIONS

There is high seismic activity on the peruvian coast due to the subduction of the Nazca plate underneath the South American plate and moderate seismic activity in the subandean zone located east of the Andes mountain.

Soil liquefaction has occurred on the coast, highlands and subandean zone in Peru. Most cases were registered on the coast because of higher seismicity and more population.

There is a correspondance between high intensities areas in Peru and soil liquefaction ocurrence. Two cases were presented one on the coast and the other in the north east of Peru.

REFERENCES

Alva-Hurtado J.E. (1983), "Brief History of Soil Liquefaction in Peru", IV Nacional Conference on Soil Mechanics and Foundation Engineering, Lima, Peru. (Spanish).

Alva-Hurtado J.E., Meneses J.F. and Guzman V. (1984). "Distribution of Maximum Seismic Intensities Observed in Peru", V National Conference on Civil Engineering, Tacna, Peru. (Spanish).

Alva-Hurtado J.E., Meneses J.F., Chang L., Lara J.L. and Nishimura T. (1992), "Ground Effects Caused by the Alto Mayo Earthquakes in Peru", Tenth World Conference in Earthquake Engineering, Madrid, Balkema, pp. 141-145.

Alva-Hurtado J.E. and Parra D. (1997), "Liquefaction Potential Map for Chimbote, Peru", Seismic Behavior of Ground and Geotechnical Structures, Sêco e Pinto (ed), Balkema, pp 25-31.

Berg G.V. and Husid R. (1973), "Structural Behavior in the 1970 – Peru Earthquake", 5th World Conference in Earthquake Engineering, Rome, Italy.

Carrillo Gil A. (1970), "Some Estimations of Soil Behavior during Ancash Earthquake", II National Conference on Soil Mechanics and Foundation Engineering, Lima-Peru. (Spanish).

Cluff L.S. (1971), "Perú Earthquake of May 31, 1970; Engineering Geology Observations", Bulletin of the Seismological Society of America, Vol 61, Nº 3, pp. 511-534.

Ericksen G.E., Plafker G. and Fernández-Concha J. (1970), "Preliminary Report on the Geological Events Associated with the May 31, 1970 Peru Earthquake", U.S. Geological Survey Circular 639.

Martinez J.M. and Machare J. (1991). "The Alto Mayo, Peru Earthquake of April 5, 1991". Technical Report for CERESIS-UNESCO, Lima, Peru. (Spanish).

Morimoto R., Koizumi Y., Matsuda T., Hakuno M. and Yamaguchi I. (1971), "Seismic Microzoning of Chimbote Area, Peru", Overseas Technical Cooperation Agency, Government of Japan, March.

Plafker G., Ericksen G.E. and Fernández-Concha J. (1971), "Geological Aspects of the May 31, 1970, Peru Earthquake", Bulletin of the Seismological Society of America, Vol 61, Nº 33, pp. 543-578.

Silgado E. (1978), "History of the Most Important Earthquakes that Occurred in Peru (1513-1974)", Institute of Geology and Mining, Journal Nº 3, Series C, Lima, Peru. (Spanish).