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Liquefaction potential map for Chimbote, Peru

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ABSTRACT: The purpose of this paper is to present the assessment of soil liquefaction potential for the City of Chimbote, Perú, based on Grade-3 method proposed by TC-4 (ISSMFE, 1993). Results were compared with soil damages produced by the May 31, 1970 earthquake. Chimbote City is located on alluvial deposits of the Lacramarca River. Soil profiles are formed by clean and silty saturated sands with densities from loose to medium. A soil exploration program was undertaken with standard penetration and dutch cone testing throughout Chimbote. Besides, data from older borings were compiled in order to get a comprehensive set of soil data for the city. A map of the city of Chimbote showing the results of superficial damage caused by soil liquefaction is presented. A good comparison of liquefaction potential sites with the damage caused by the May 31, 1970 earthquake is obtained.

INTRODUCTION

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 at a distance of about 400 kilometers north of Lima, the capital of Peru. (Alva-Hurtado, 1983).

On May 31, 1970 an earthquake of magnitude Ms=7.8 and focal depth of 45 kilometers occurred west of Chimbote. The epicenter was located 50 km off the coast. A strong motion record of the earthquake was obtained in Lima, with a maximum horizontal acceleration of 0.11 g. No record was obtained in Chimbote. Maximum intensity of IX in the Modified Mercalli Scale was determined.

Several soil borings were made in Chimbote after the May 31, 1970 earthquake (Morimoto et al, 1971;Carrillo, 1972; Parra, 1990), so it was possible to apply the Manual for Liquefaction Zonation of the Technical Committee for Earthquake Geotechnical Engineering of the ISSMFE. A design earthquake similar to the May 31, 1970 earthquake was used, resulting in good agreement between the liquefaction predicted and the soil effects produced by the quake.

SOIL LIQUEFACTION CAUSED BY 1970 EARTHQUAKE

A brief summary on 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 in Chimbote, lateral spreading of the ground caused by liquefaction of deltaic and beach deposits was produced. Cracks were observed on the ground that affected structures. 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 in the surface, because of liquefaction, was noticed.

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 superficial. Berg and Husid (1973) verified the occurrence of soil liquefaction in the foundation of the Mundo Mejor school in Chimbote.

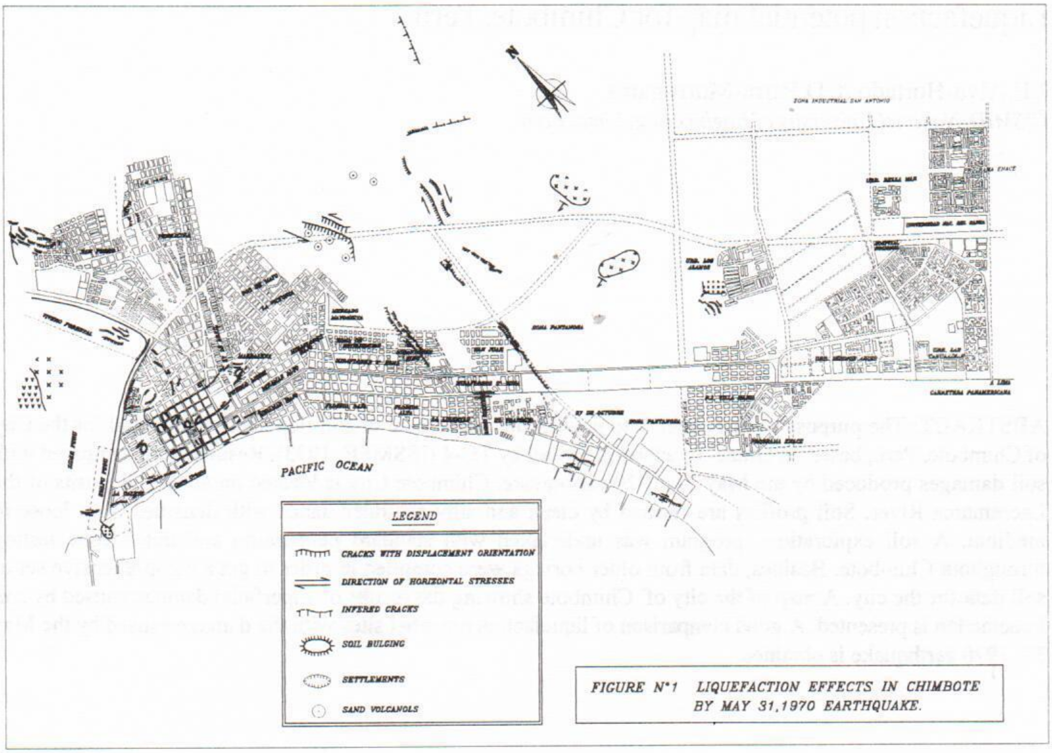

FIGURE N°1 LIQUEFACTION EFFECTS IN CHIMBOTE BY MAY 31,1970 EARTHQUAKE.

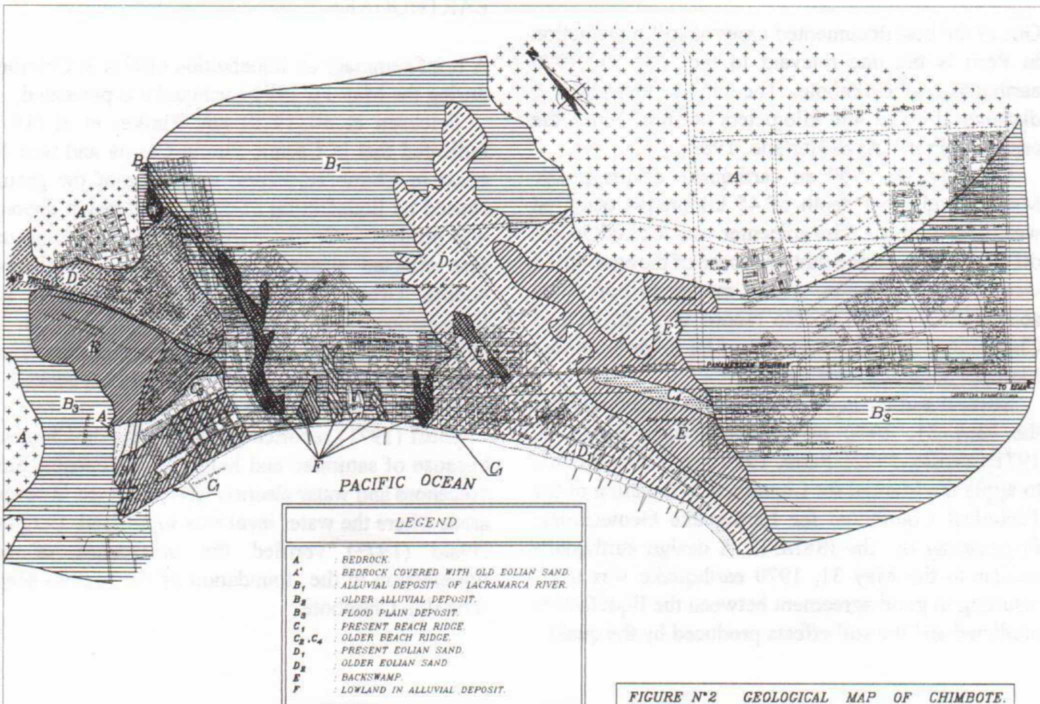

FIGURE N°2 GEOLOGICAL MAP OF CHIMBOTE.

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 (Fig N°1). In the backswamps and lowlands in alluvial deposit, general liquefaction was developed with cracks due to differential compaction of soil deposits. In the alluvial deposit, subsurface liquefaction developed, generating cracks with sand volcanoes and damage to wells.

GEOTECHNICAL CHARACTERISTICS OF CHIMBOTE

Geology of the area is composed of bedrock and quaternary deposits. The rocks are Cretaceous andesitic volcanic with shale and sandstone and granitic intrusive rocks. Quaternary deposits are alluvial, beach ridges, eolian sands and backswamps. To the north and southeast of the city there are rocky mountains and hills which are covered partly with eolian sand. Chimbote is located on the alluvial plain of the Lacramarca River (Fig N°2).

The subsoil of Chimbote consists mainly of a thick sandy deposit with superficial water. The deposit is likely to suffer liquefaction and densification under seismic excitation. In most parts of the city the sand is medium to dense, with N values of 10 to 30, overlying very dense sands or gravel down to bedrock. However, in some areas, high water level and N values lower than 10 are found.

The northern part of the city includes the districts of San Pedro, Pensacola, Casco Urbano, La Caleta and Siderúrgica. In San Pedro the soil profile consists of loose to medium sand with the water level at 5.0 meters. In Siderúrgica there are medium to fine sand deposits with lenses of silt and gravel, covered by organic fill with the water level at 0.5 to 1.0 meters. Values of N range from 5 to 10 at the surface, increasing in value with depth. Casco Urbano is composed of fine to medium sand with caliche and gravel layers. The water level is at 1.50 meters. Value of N vary from 10 at the surface to over 50 at 5.0 meters in depth. La Caleta and El Puerto are characterized by loose silty sands with organic matter; the thickness goes from 1.5 to 4.0 meters, overlying medium compacted sands and gravels.

The central zone includes the areas known as Urb. 21 de Abril, Pueblo Libre, Villa María Baja, Miraflores, Miramar Alto and Miramar Bajo, Florida Alta and Florida Baja, La Libertad and Trapecio. In Miramar Bajo there is organic material at the surface, with fine to medium sand down to 10 meters, silty sand down to 20 meters and then gravel. Water level varies from 0.70 to 1.40 meters. In Miraflores values of N range from 8 to 12 at 2.0 meters, reaching 40 at 4.0 meters. The soil profile in Trapecio consists of fine and silty sands with seashells with a thickness of 4 to 6 meters. The sand overlies dense sand with clay and gravel layers.

In 27 de Octubre there is fine sand with the water level at 1.0 meters. In Villa María Baja the soil profile shows has fill at the surface overlying loose to medium sand with a high water level.

The southern part includes the districts of Villa María Alta, Buenos Aires, Nuevo Chimbote, Casuarinas and Canalones. The water level is below 16 meters in this area. The ground is composed of coarse to fine sand with gravel. In Buenos Aires the coarse to fine sand layer has a thickness of 20 meters whereas in Nuevo Chimbote it has a thickness of 4 meters, overlying fine to medium sand with clay down to 16 meters. Standard penetration values obtained were higher than 12 at the surface, increasing in value with depth.

CHIMBOTE SEISMIC MICROZONATION

Seismic microzonation of Chimbote was undertaken by Morimoto et al (1971) based upon geology, standard penetration testing, damage evaluation, aftershocks and microtremors, seismic refraction and soil amplification studies. Four different zones were established (Fig N°3).

Zone I. The ground consists of dense gravel or rock with the water level at least 10 meters below ground surface. The elevation of the ground is above 10 m.a.s.l. Subsidence of buildings or ground is not expected. Larger seismic forces are expected in this zone because of soil structure interaction.

Zone II. This area is covered by loose to medium sand several meters thick. Below there is either dense sand or cemented sand. Water level is about 5 meters below surface. No settlement is expected for two-story buildings, except those at the outer edge of sand dunes. It is recommended that buildings higher than

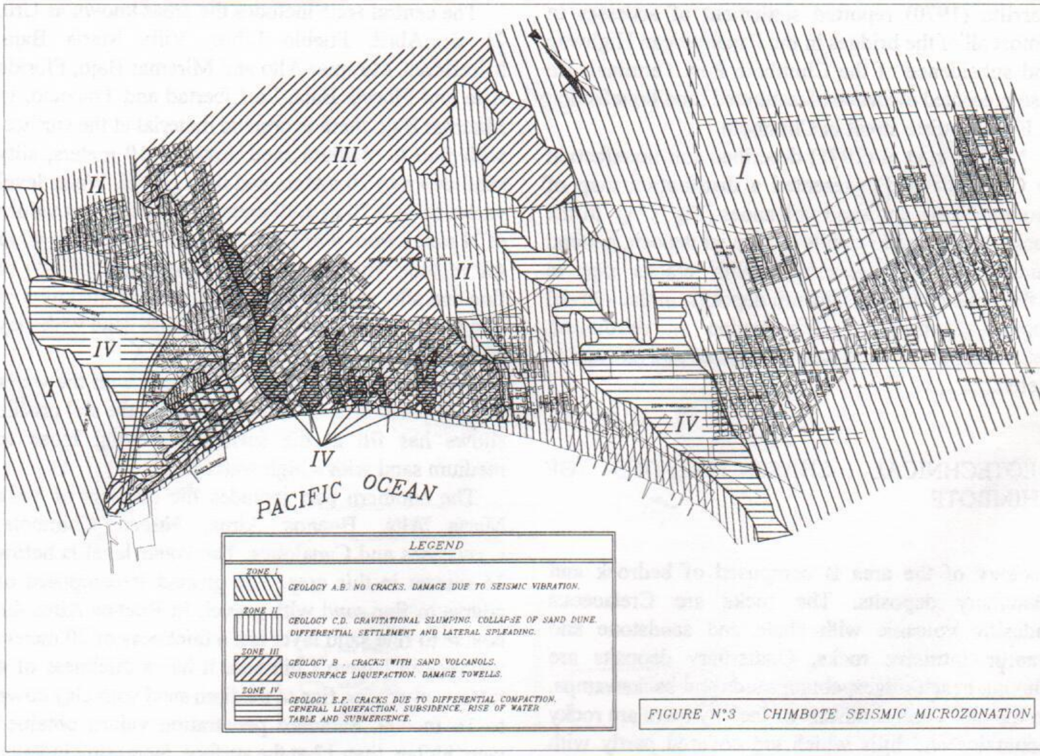

FIGURE N°3 CHIMBOTE SEISMIC MICROZONATION

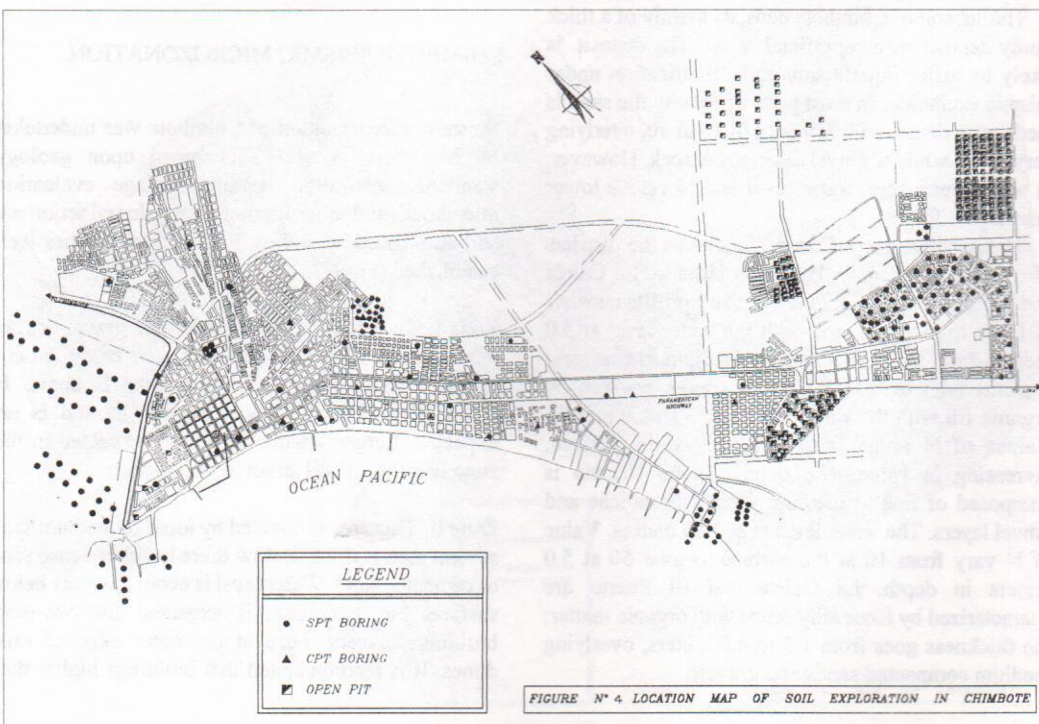

FIGURE N° 4 LOCATION MAP OF SOIL EXPLORATION IN CHIMBOTE two stories be supported by piles reaching the dense sand. Construction on sand dunes must be improved with vibroflotation.

Zone III. The soil profile is formed by sandy soil covered by thin agricultural soil. Gravel is found below 10 meters, with a shallow water level. Loose fine sand existing at different depths may liquefy during earthquakes. However no appreciable settlements will occur in building, except special cases.

Zone IV. This zone has a high water table. Most of the land is covered with water or swamps. Average elevation of the land is lower than 5 m.a.s.l. The soil profile consists mainly of sand covered with a very thin layer of organic silt. Damage to buildings is mainly by settlement and partly by seismic force. Liquefaction of the sand up to the surface will be produced by a severe earthquake. Pile foundations down to dense sand or improvement of the ground conditions, are recommended.

GEOTECHNICAL INVESTIGATION

Alva-Hurtado and Parra (1991) compiled data from standard penetration tests and open pits, carried out in Chimbote by public and private organizations after the May 31, 1970 earthquake. In addition a geotechnical investigation program was undertaken.

The research program consisted of 11 standard penetration and 9 dutch cone tests throughout Chimbote, to add information to the available soil data bank. SPT tests were made by wash boring and casing. Tests were made every meter, down to depths of 4 to 11 meters. Disturbed samples were obtained for soil classification. CPT tests were performed with a portable equipment with a 2-ton capacity. Cone penetration was recorded every 20 cm up to 6 meters in depth. Manual auger exploration was made near the CPT test sites to get soil samples for classification. Fig N°4 presents the area of the geotechnical study in Chimbote.

LIQUEFACTION POTENTIAL EVALUATION

The evaluation of liquefaction potential in Chimbote was undertaken by the application of the Grade-3 method proposed by TC-4.

A design earthquake with a magnitude of Ms=7.5 and a maximum acceleration of 0.3 g was used in the evaluation. Dutch cone results were converted into N values according to Robertson and Campanella (1983, 1985). Overburden correction was made with the formula given by Liao and Whitman (1986).

With the information from soil profiles and the design earthquake, the simplified method of liquefaction potential was used. The method proposed by Seed et al (1983) and Seed and De Alba (1986) was applied for SPT and CPT borings. Prof. Ishihara's (1985) criteria for damage in the presence of an unliquefiable surface layer was also included in the evaluation. Fig N°5 presents the potential liquefaction damage at ground surface for an earthquake with maximum acceleration equal to 0.30 g.

Liquefaction will occurr in the central part of Chimbote: Dos de Mayo, La Victoria, Alto Peru, Zona de Reubicación, Miraflores Alto, Miraflores 1st and 3rd zone and part of Florida Baja. These districts are located on the alluvial deposit of the Lacramarca River. The soil profile shows a superficial thin layer (silt and clay) over loose sand, that increases its compactness with depth, and has thin layers of clay. Water level is at the surface. Liquefaction will also occur in the districts of San Juan, Urb. Trapecio, Barrio Magisterial in the south and in part of Miraflores 2nd zone. These sites are of loose eolian sand at the surface, increasing in density with depth. Water level is at 1.5 to 2.0 meters. In the northern part, Miramar Bajo and La Caleta districts, the phenomena of liquefaction will occur. The soil profile shows fine and silty sands with a high water level. The backswamp zone that exists to the north and to the south of Chimbote will also liquefy.

Fig N°5 presents a map of Chimbote showing the results of the liquefaction potential evaluation. Comparison of liquefaction potential sites with damage caused by the May 31, 1970 earthquake, as presented in Fig N°1, shows good cor relation.

CONCLUSIONS

The soil liquefaction phenomena that ocurred in the city of Chimbote during the May 31, 1970 earthquake was documented.

Boring logs performed after the earthquake by public and private organizations were compiled. In addition, a soil exploration program was undertaken by means of standard penetration and dutch cone testing. An important soil data bank was obtained for Chimbote to be used in its future development.

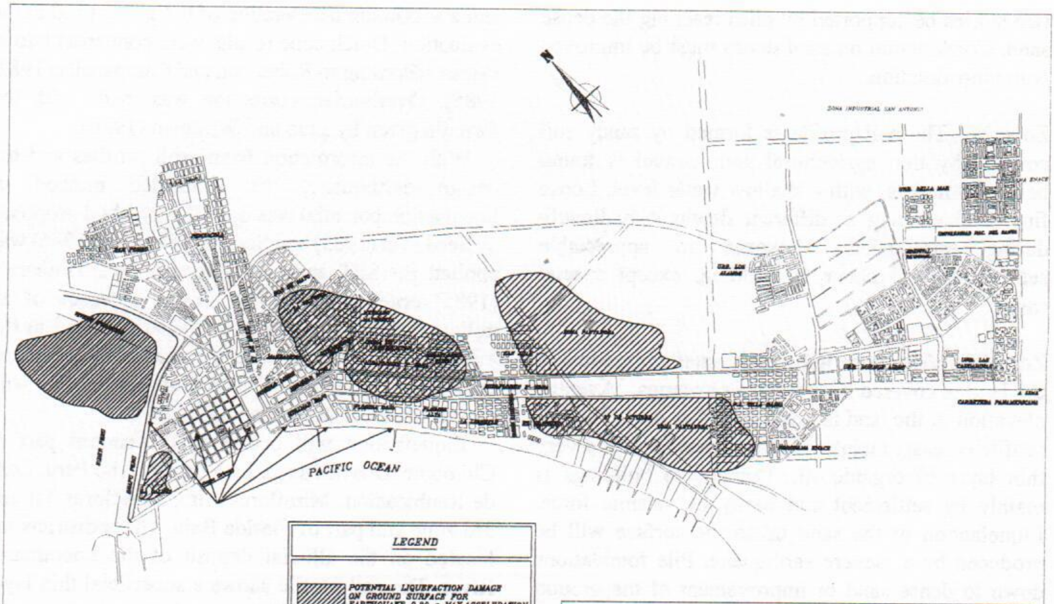

FIGURE N°5 LIQUEFACTION POTENTIAL MAP OF CHIMBOTE.

A case study for the application of the Manual for Zonation on Seismic Geotechnical Hazards proposed by TC-4 of ISSMFE was possible with the soil information and soil liquefaction damage available in Chimbote.

A good correlation was obtained between the predicted potential liquefaction areas in Chimbote and the actual soil damage produced by the May 31, 1970 earthquake.

REFERENCES

Alva Hurtado J.E. and Parra D. (1991), "Evaluación del Potencial de Licuación de Suelos en Chimbote, Perú". IX Congreso Panamericano de Mecánica de Suelos e Ingeniería de Fundaciones, Viña del Mar, Chile.

Alva Hurtado J.E. (1983), "Breve Historia del Fenóeno de Licuación de Suelos en el Perú", IV Congreso Nacional de Mecánica de Suelos e Ingeniería de Fundaciones, Lima, Perú.

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

Carrillo Gil A. (1970), "Algunas Apreciaciones del Comportamiento del Suelo en la Zona del Sismo de "Ancash", II Congreso Nacional de Mecánica de Suelos e Ingeniería de Fundaciones, Lima, Perú.

Carrillo Gil A. (1972), "Estudio de Suelos para Cimentación y Pavimentación", Plan Director de Desarrollo de Chimbote PNUD, Chimbote, Perú.

Cluff L.S. (1971), "Perú Earthquake of May 31, 1970; Engineering Geology Observations", Bulletin of the Seismological Society of America, Vol. 61, N°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 Perú Earthquake", U.S. Geological Survey Circular 639.

Ishihara K. (1985), "Stability of Natural Deposits During Earthquakes", Proc. 11th Int. Conf. on Soil Mechanics and Foundation Engineering, San Francisco, Vol I, pp 321-376.

ISSMFE (1993), "Manual for Zonation on Seismic Geotechnical Hazards", Technical Committee for Earthquake Geotechnical Engineering, TC4, The Japanese Society of Soil Mechanics and Foundation Engineering.

Liao S. and Whitman R.V. (1986), "Overburden Correction Factors for SPT in Sand", Journal of Geotechnical Engineering ASCE, March, pp 373-377.

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

Parra D. (1990), "Evaluación del Potencial de Licuación de Suelos de la Ciudad de Chimbote", Tesis de Grado, Universidad Nacional de Ingeniería, Lima, Perú.

Plafker G. Ericksen G.E. and Fernández-Concha J. (1971), "Geological Aspects of the May 31, 1970, Perú Earthquake", Bulletin of the Seismological Society of America, Vol 61, N°33, pp 543-578.

Robertson P.K. and Campanella R.G. (1983), "Interpretation of Cone Penetration Test Part I: Sand" Canadian Geotechnical Journal, Vol 20, pp 718-733.

Robertson P.K. and Campanella R.G. (1985), "Liquefaction Potential of Sands Using the CPT", Journal of the Geotechnical Engineering Division, ASCE, Vol 111, N°3, pp 384-403.

Seed H.B., Idriss I.M. and Arango I. (1983). "Evaluation of Liquefaction Potential Using Field Performance Resistance of Sands", Use of Insitu Test in Geotechnical Engineering, ASCE, pp 281-302.

Seed H.B. and De Alba P. (1986), "Use of SPT and CPT Tests for Evaluating the Liquefaction Resistance of Sands", Use of Insitu Test in Geotechnical Engineering, ASCE, pp 281-302.