H/V MICROTREMOR MEASUREMENTS IN PISCO, PERU AFTER THE 2007 AUGUST 15 EARTHQUAKE

J. A. T. Johansson[1], E. A. Leon Mahecha[2], A. T. Torres Acosta[2], and J. P. Mayorca Arellano[3]

[1] *Associate Professor, Institute of Institute of Industrial Science, University of Tokyo, Tokyo, Japan*
[2] *Graduate Student, Institute of Institute of Industrial Science, University of Tokyo, Tokyo, Japan*
[3] *Project Assistant Professor, Institute of Institute of Industrial Science, University of Tokyo, Tokyo, Japan*
Email: jorgen@iis.u-tokyo.ac.jp, paola@iis.u-tokyo.ac.jp

ABSTRACT :

The 2007 August 15, Pisco, Peru earthquake caused a lot of damages to both adobe dwellings and substandard engineered buildings in Pisco. Liquefaction was wide spread in the city, with very large deformations observed in the areas closest to the ocean. Existing seismic wave amplification studies, based on soil classification, SPT and ground water levels, have identified 3 zones in Pisco, with amplification levels varying from 1.5 to more than 3. However, the distribution of MSK intensities, reported by Agüero et. al., differed somewhat from the above zonation. During our damage survey of Pisco we performed microtremor measurements at 34 points, collaborating with the Japan-Peruvian Centre of Seismic Investigations and Disaster Mitigation (CISMID). Our H/V evaluated frequencies are in fair agreement with the lithology and geotechnical characteristics and the frequencies distribution coincide partially the with MSK intensities. We hope our findings can complement the existing zonation and hazard maps.

KEYWORDS: Pisco earthquake, microzonation, microtremor, hazard map

1. INTRODUCTION

On August 15, 2007 at 18:41, a large earthquake (Magnitude, Mw=8.0) hit the central part of Peru's coast, some 150 km south of Lima. The Peru Geophysics Institute (IGP) estimates Modified Mercalli Intensities of VII-VIII in Pisco, Chincha, and Ica. The earthquake tragically resulted in 519 deaths, 1,291 injured, and more than 650,000 affected people. Totally, some 80,000 dwellings and buildings were damaged or completely destroyed in the regions of Ica, Lima, Huancavelica, Ayacucho and Junín. The duration of the earthquake was very long with over 2 minutes of strong ground shaking at Ica. The local/Richter magnitude computed by IGP was 7.0 (ML). (The use of different magnitude by seismologists caused confusion since laymen take them for the same thing, which they are not. This confusion was amplified by a rumor that reconstruction financial support would depend on the magnitude). A tsunami exacerbated the damage already caused by shaking and ground failures.

To help in the evaluation of damage and to obtain data useful for both reconstruction and long-term planning of the Pisco city, our team collaborated closely with CISMID (Centro Peruano Japonés de Investigaciones Sísmicas y Mitigación de Desastres) of the National University of Engineering, Lima, to perform microtremor measurements in Pisco. We also shared our data with the team from INGEMMET (Peruvian Institute for geology, mining and metallurgy [9]).

2. BRIEF DESCRIPTION OF DAMAGE OBSERVED IN PISCO

According to the National Institute of Civil Defense (INDECI) the death toll in the city was 338, 70% of the whole earthquake dead toll, as of October 10, 2007 [3]. The most spectacular part of the damage was the complete destruction of the San Clement church, which caused 30% of the fatalities in this earthquake. Pisco is located directly above the central part of the estimated fault plane (see e.g. [1]) and a local intensity of 8- (MSK-64) was estimated by Agüero et. al. [5] (see Figure 1), who evaluated the damage to some 30 buildings. Below, we compare this figure with our microtremor result.

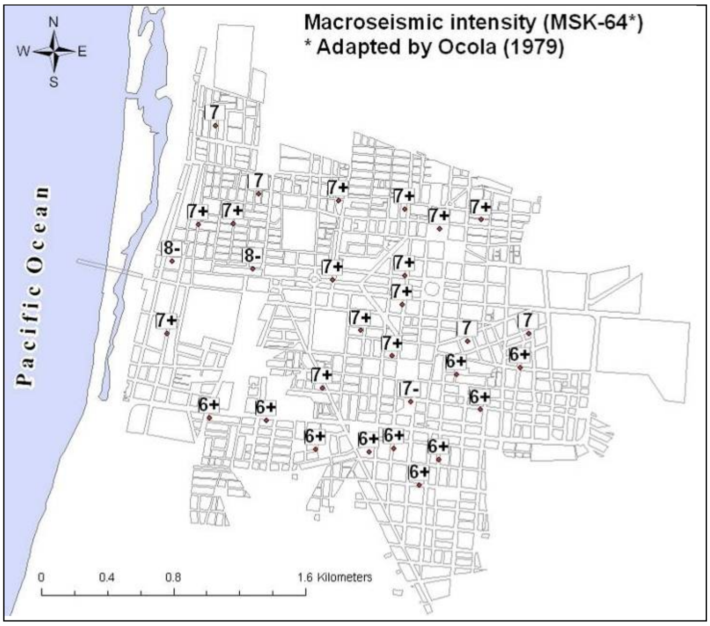


Figure 1. Macroseismic intensity (MSK-64) distribution (adapted from Agüero et .al. [5]).

Liquefaction induced lateral spreading caused a lot of damage in the western parts of Pisco, which are closest to the ocean, where the ground water level is high and the soil is poorly graded. Ground cracks several meters long and decimeters wide cracked the confined masonry structure shown in Figure 2.

Figure 2. Soil displacement crack next to old building. The crack probably continues in front of and/or beneath the building and then up through the confined masonry wall as marked by the black arrow. (The curvature of the building top is due image distortion, it should be a straight line.)

The sewage system in Pisco, whose conditions were already poor before the earthquake, was drastically affected due to ground deformation and liquefaction. As shown in Figure 3, broken sewage pipes which caused ground settlements, and pushed-up manholes were widely observed in Pisco. The engineers at a temporary city office were trying to cope with cascading failures. We were told they repaired in one location and as soon as they pressurized the system, the pipes in other locations would fail. Unfortunately a map with pipe failure locations was not available at the time of our visit. Such a map would be useful to compare with the other figures shown below as to evaluate the relation between local geology and the pipe damage.

Figure 3. Central and southwest areas of Pisco had broken sewer pipes causing ground settlements and pushed up manholes were observed in many locations.

3. GEOTECHNICAL DESCRIPTION OF PISCO

The geology of Pisco can be divided into two main formations [7, 8]. The oldest is the Pisco formation (yellow in Figure 4), a lithologic sequence of white color composed of diatomite with intercalation of tuff sandstones and shales, located between the Pisco River and the surroundings of Camana. The other formation consists of recent quaternary deposits, composed of clastic materials transported by water and then deposited on the river beds as coarse conglomerates intercalated with sand, silt and clay. These deposits can be observed along the river side and the terraces' foot. The main part Pisco city is located on alluvial deposit, whereas its southern part is located on an eolian deposit.

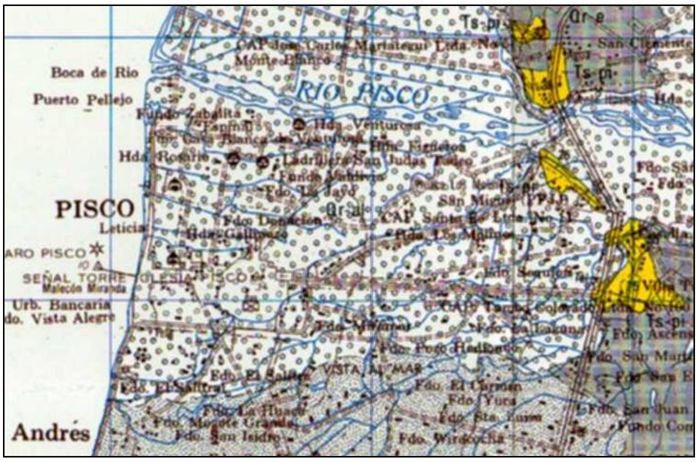


Figure 4. Geological map of Pisco and surroundings (after [8]).

Figure 5 shows a geotechnical classification of the soil deposit in Pisco (after [6]). Poorly graded sand is found Along the coast (marine deposits) and in the northern part (Pisco river deposits). In the central part there is well graded sand and towards the east there is silty sand. To the south and the south-east gravelly soils are found. In general the ground water level is high in the central, coastal and northern part of the area; it fluctuates between 0.5-2 meters. In the southern area the ground water level is found around 2-3.5 meters depth. In the eastern part the ground water level is below 3.5 m.

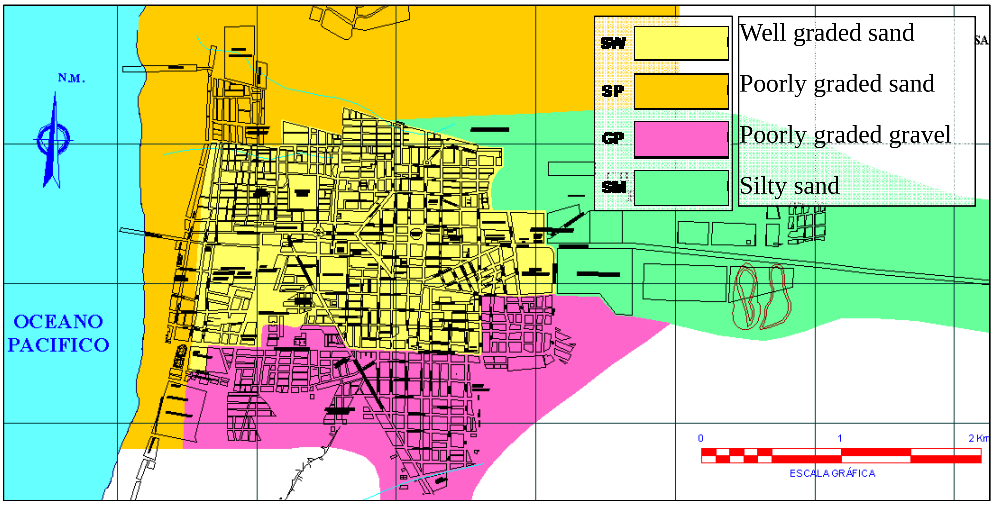


Figure 5. Pisco soil classification (after [6]).

4. MICROTREMOR MESUREMENTS IN PISCO

We (hereafter UT) have collaborated with CISMID of the National University of Engineering (hereafter UNI) to perform a microzonation of the city of Pisco (during September 15 and 16, 2007) with microtremor measurements at 34 different points in the city (see Figure 6). Both teams used a Geodas-10 recording equipment with CR-4.5-1 velocimeter (UNI) and CR-4.5-2S velocimeter (UT), The frequency range of 0.5-2.0 Hz for UT's velocimeters whereas 1.0-2.0 Hz for UNI's. At each location two sensors were used simultaneously for two 3 minute observations (100 Hz sampling frequency). At the same time we also coordinated with an INGEMMET team [9] who also measured microtremors in Pisco and later we shared our data sets.

All the data was processed with same criteria using the software Geopsy [4] and Figure 7 (left) shows the H/V ratio (HVSR) determined frequencies for all points. Out of 34 points, eleven did not show any clear peak, e.g. the zone of amplification was too broad to distinguish a peak, or the peak was split into two or three parts, or the amplification was less than 2. Out of the remaining 23 points, 6 points had frequency peak beyond the sensor range, which however may be accepted to a certain level since we are using the ratio of the horizontal and vertical Fourier spectra. Furthermore, the UNI team (and also the Ingemmet team, [9]) obtained similar results at locations nearby to the locations with such high frequencies.

5. RESULTS AND DISCUSSION

In Figure 7 blue circles mark observations sites with easily identified peaks, while the red circles mark the ones with less distinct peaks. Based on the reliable points (blue circles), a straightforward spline-type interpolation depicts a North-West to South-East trend of increasing frequencies.

Figure 8a) shows the H/V amplification values with asterisks marking the location of points for which it was difficult to identify the peak and with question marks marking points where the peak frequency were out of the sensor range. Figure 8b) shows the interpolated contours again with blue circles marking observations sites with easily identified peaks, while the red circles mark the ones with less distinct peaks. It is difficult to identify a general pattern and the influence of the non-reliable points may change the geometry of these contours. However, there are higher levels of amplification in the central part and towards the coast.

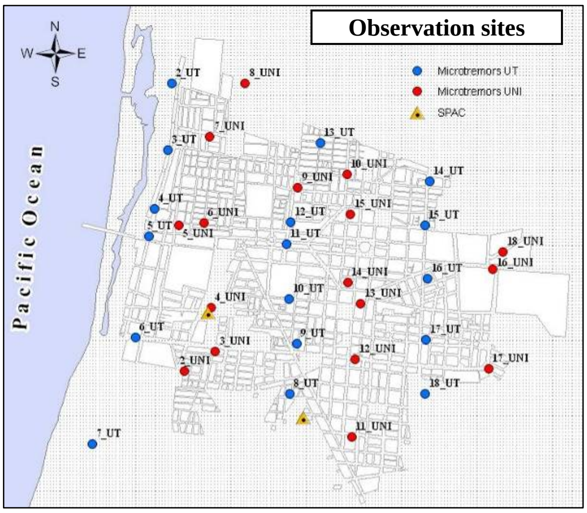


Figure 6. UNI's (National University of Engineering, Lima) and University of Tokyo's microtremor observation sites.

Figure 9 shows the MSK intensities from Figure 1 plotted on top of H/V frequencies contours. There is partial agreement between the location of the 6+ intensities and the location of higher frequencies in the South-east part of Pisco.

The H/V frequencies (see Figure 7) reflects well the geological/geotechnical description (see Figure 4 and Figure 5) and become very high when moving towards the eolian deposit in the south. The geotechnical description says that south-east soil deposit consists of about 1 m thick layer of clayey gravel above a poorly graded gravel. In the central part and toward the coast where the soil are softer well and poorly graded sands ([6], see Figure 5.) the H/V frequencies are relatively low.

In the south-east parts of Pisco the MSK intensities (see Figure 1) are 6+ coincide with the very high H/V frequencies (see Figure 7). In general the adobe buildings in Pisco should have natural frequencies beneath 15 Hz. Since the natural ground frequency is above this value in the south-east it is possible that ground shaking contained mainly frequencies that would damage the buildings to a smaller degree, hence the lower MSK intensities. I.e. so called resonance effects were reduced. On the other hand the 7+ or 8- MSK intensities are within or near the clear yellow area in **Figure 9** (frequencies 5-10 Hz).

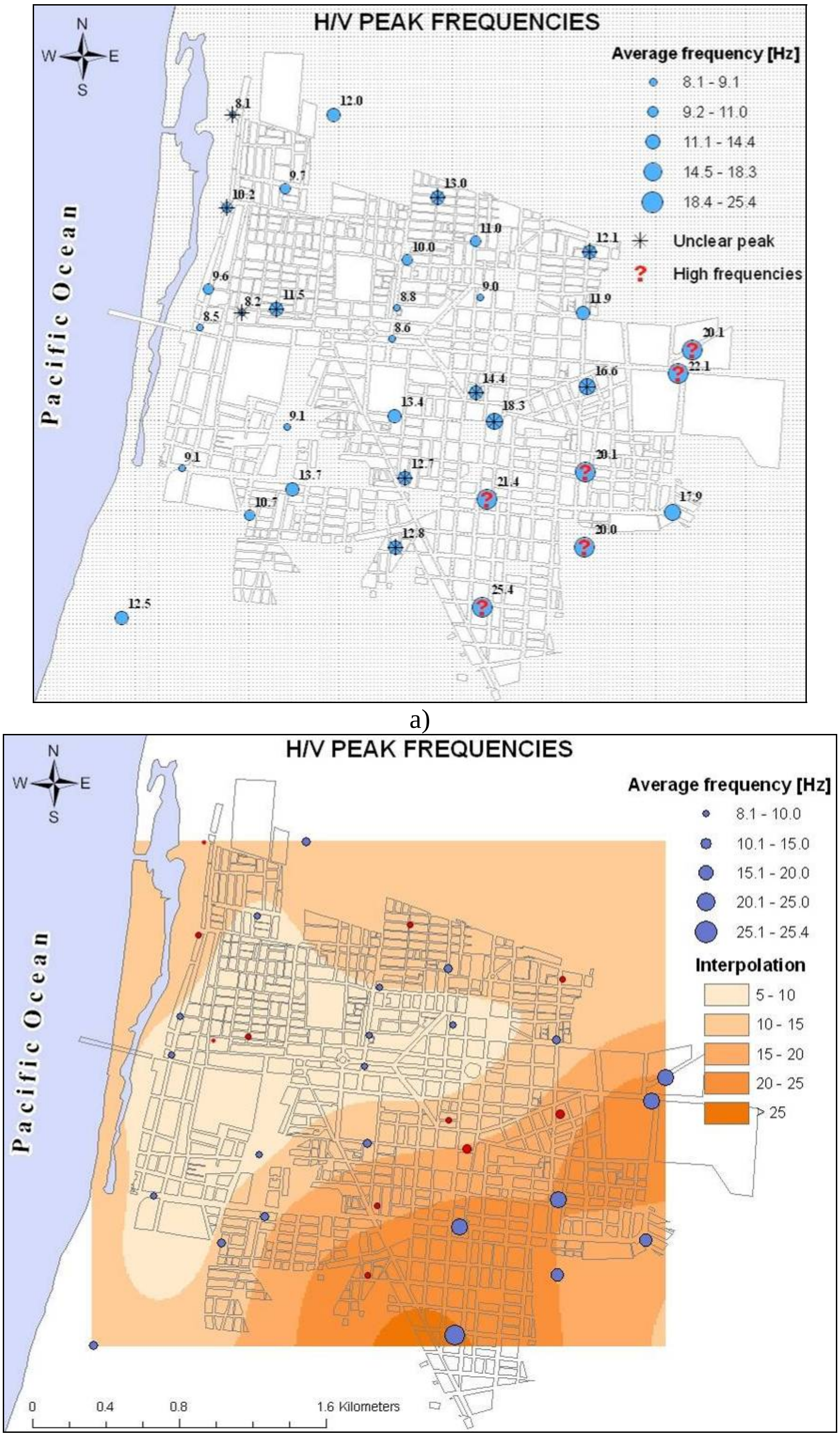
6. FINAL REMARKS

The above observations indicate the importance of evaluating the geotechnical properties and taking them into account both in land-use planning and in the design of buildings. Such efforts have been underway in Peru, e.g. in the last 10 years with the Sustainable Cities Program (see e.g. the website of The National Institute of Civil Defense [3] and papers [10-11]), and at many organizations with whom we also had a chance to collaborate with.

Finally we hope that our own results can contribute a little bit to development of Peru.

ACKNOWLEDGMENTS

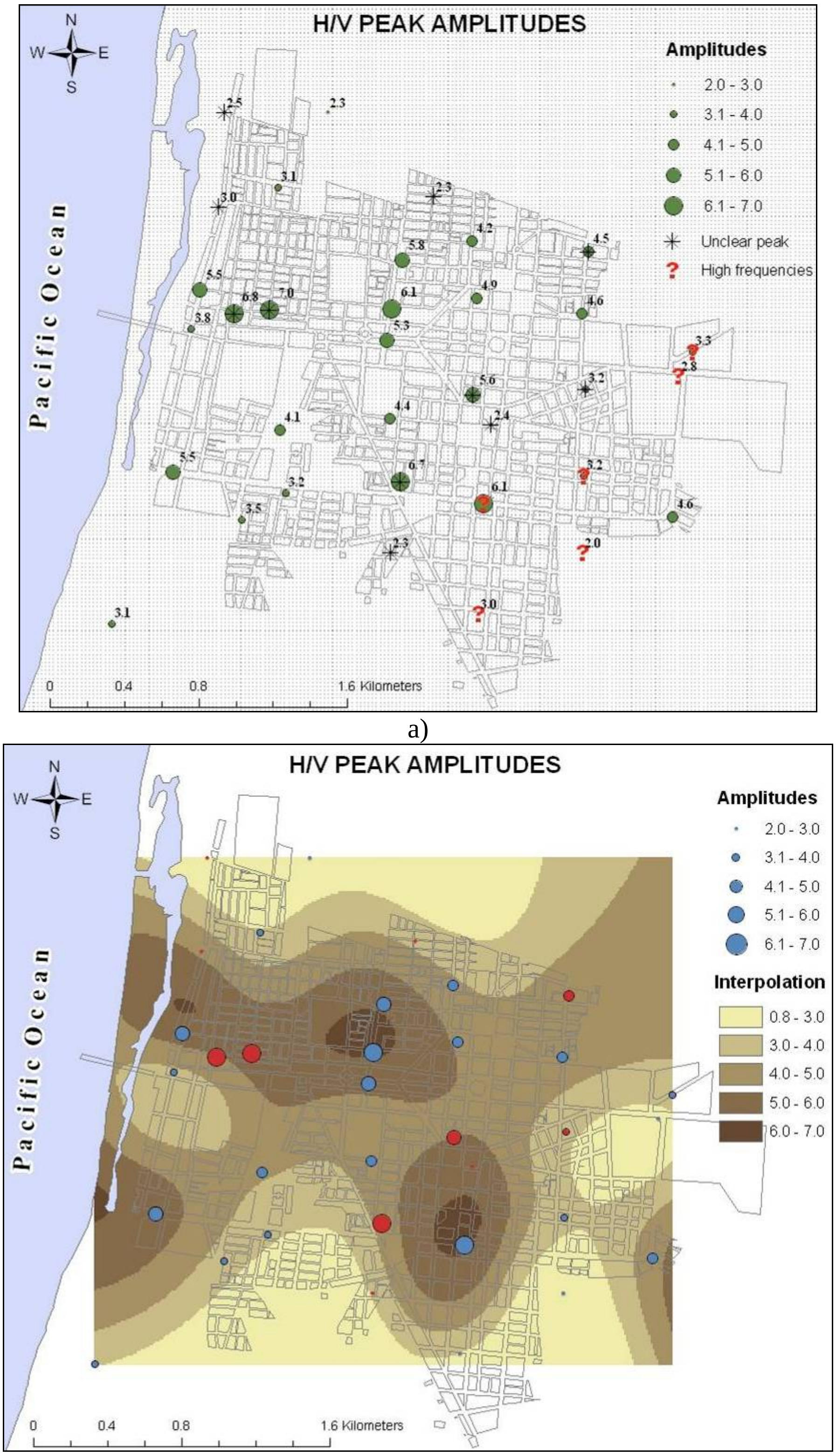
We would like to thank JSCE and JAEE for the support for the funding to perform this study. We also appreciate very much all the help we received from the collaborators and many other persons we met during our stay in Peru. (See the online report [1] for a full list of names.)



a)

b)

Figure 7. H/V peak frequencies and interpolation color contours. In b) Blue circles mark observations sites with easily identified peaks, while the red circles mark the ones with less distinct peaks.



a)

b)

Figure 8. H/V peak amplitudes and interpolation color contours. In b) Blue circles mark observations sites with easily identified peaks, while the red circles mark the ones with less distinct peaks.

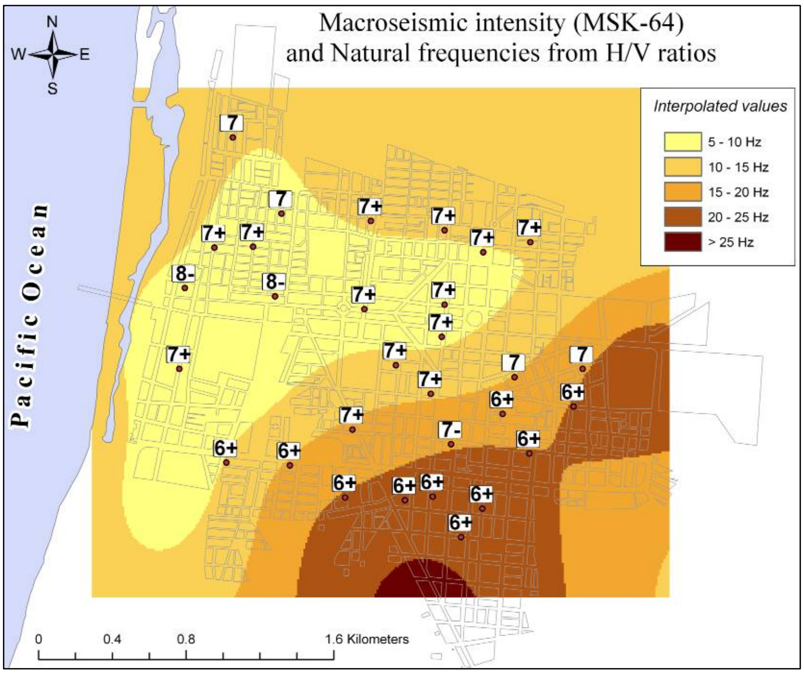


Figure 9. MSK intensities plotted on top of H/V frequency contours.

REFERENCES

1. Jörgen Johansson, Paola Mayorca, Tatiana Torres, and Edwin Leon (2007), A Reconnaissance Report On The Pisco, Peru Earthquake Of August 15, 2007, http://shake.iis.u-tokyo.ac.jp/Peru2007/JSCE_JAEE_Report/Index.htm
2. Astroza M. Intensities and earthquake induced damages. Report on affected areas by the earthquake of August 15th, 2007. Available on http://www.ceresis.org/informacion/ (In Spanish)
3. National Institute of Civil Defense. Annex of emergency report No 336 “Ica and South of Lima departments severely affected by seismic movement”. Available on www.indeci.gob.pe. (In Spanish).
4. http://www.geopsy.org/
5. Agüero C, Tavera H, Fernandez E, Huaco P, Talavera C and Arredondo L. Macroseismic intensities in the urban area of Pisco regarding the earthquake of August 15, 2007. Preliminary version. Geophysical Institute of Peru. http://khatati.igp.gob.pe/Webs/cns06/pisco2007/terremoto_pisco_2007.htm (in Spanish)
6. Aguilar Z., Erasmo Matos Espinoza, Ruben Cangana Gutierrez, and Vladimir Ferro Ameri, (2006) Geotechnical microzonation of Pisco. National University of Engineering. Semester Report for the course “Disaster management for sustainable development” of Territorial Studies. Lima, Peru.
7. Sanchez M, Parra D, De la Cruz K. Seismic microzonation of Pisco city. CISMID-UNI Geotechnical laboratory. 1999 (In Spanish).
8. INGEMMET, (1999), Geological map, quadrangle 27k, 1999, www.ingemmet.gob.pe
9. Lionel Fídel Smoll, Yanet Antayhua Vera (2007), INGEMMET, personal communication, www.ingemmet.gob.pe.
10. Kuroiwa, Julio (2002), Sustainable Cities, a Regional Seismic Scenario, and the 6-23-2001 Arequipa Peru Earthquake, Natural Hazards Review, Vol. 3, No. 4, November 2002, pp. 158-162, (doi 10.1061/(ASCE)1527-6988(2002)3:4(158))
11. Kuroiwa Julio, (2008), Reconstruction of Ica, Pisco, Chincha and Cañete, Peru,. Based on Updated Hazard Maps, Proc. of Sixth National Seismic Conference on Bridges & Highways, Charleston, SC, July 27-30