Nasca earthquake, November 12, 1996, Peru

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ABSTRACT: The main features of the November 12, 1996 earthquake produced in the Nasca region in southern Peru are presented. A summary of damage evaluation and seismic microzonation undertaken by several national and international institutions is also presented.

INTRODUCTION

A moderated earthquake occurred on Tuesday, November 12, 1996 in the Nasca-Acari region, 450 km. south of Lima. The earthquake was produced by the subduction of the Nasca plate underneath the South American plate. The epicenter was located 135 km. south west of the city of Nasca

Nasca and Acari were the cities most affected, as well as several towns in the highlands where damage was extensive in adobe buildings. Many new and old adobe houses collapsed. Damage was observed in concrete buildings mainly recently built state schools.

Seventy five percent of the houses in the region were built with adobe. Official damage reports indicated that 14 persons dead, 624 were injured, 4,000 houses were destroyed, 11,000 were partially damaged, 91 schools and 100 health centers were damaged in the epicentral area.

SEISMOLOGY

The earthquake started at 11:59 a.m., local time, on the border between the Departments of Ica and Arequipa in southern Peru. The Geophysical Institute of Peru (IGP, 1977) calculated a magnitud of 6.3 based on duration of the earthquake (1'58"), with epicentral coordinates at 15.47°S and 75.94° W and a focal depth of 40 km. The corresponding USGS magnitudes are mb= 6.5, Ms = 7.3 and Mw = 7.7, with a focal depth of 33 km and epicentral coordinates at 14.99°S and 75.68°W. Figure 1 presents IGP's epicentral calculation.

This earthquake originated at the southern end of the seismic gap between the August 24, 1942 and October 3, 1974 earthquakes. Aftershocks progressed to the south, towards the 1942 earthquake area. The event was complex with at least two major events that occurred 20 and 33 seconds after the first shock (IGP, 1997).

According to historical seismicity data (Silgado, 1978, Alva Hurtado et al., 1984) a maximum intensity of IX in the Mercalli Modified scale was produced in the region by the August 24, 1942 earthquake. This subduction earthquake had a magnitud M_s= 8.1 and a focal depth of 60 km. with epicenter in the sea.

Strong motion records were obtained in Lima during the 1996 earthquake with maximum acceleration from 7 to 10 gals because of the long distance to the epicenter. No records closer to the epicenter were obtained.

REGIONAL AND LOCAL INTENSITIES

A regional intensity map, MSK scale (Figure 2) for the November 12, 1996 earthquake was presented by the Geophysical Institute of Peru (Ocola et al, 1997).

The maximun intensity of 7^+ (MSK scale) was observed in the Yauca river estuary. Along the shore line between Yauca and San Nicolas, cracks were observed as well as along the shoulders of the adjacent Panamerican Highway. Soil liquefaction

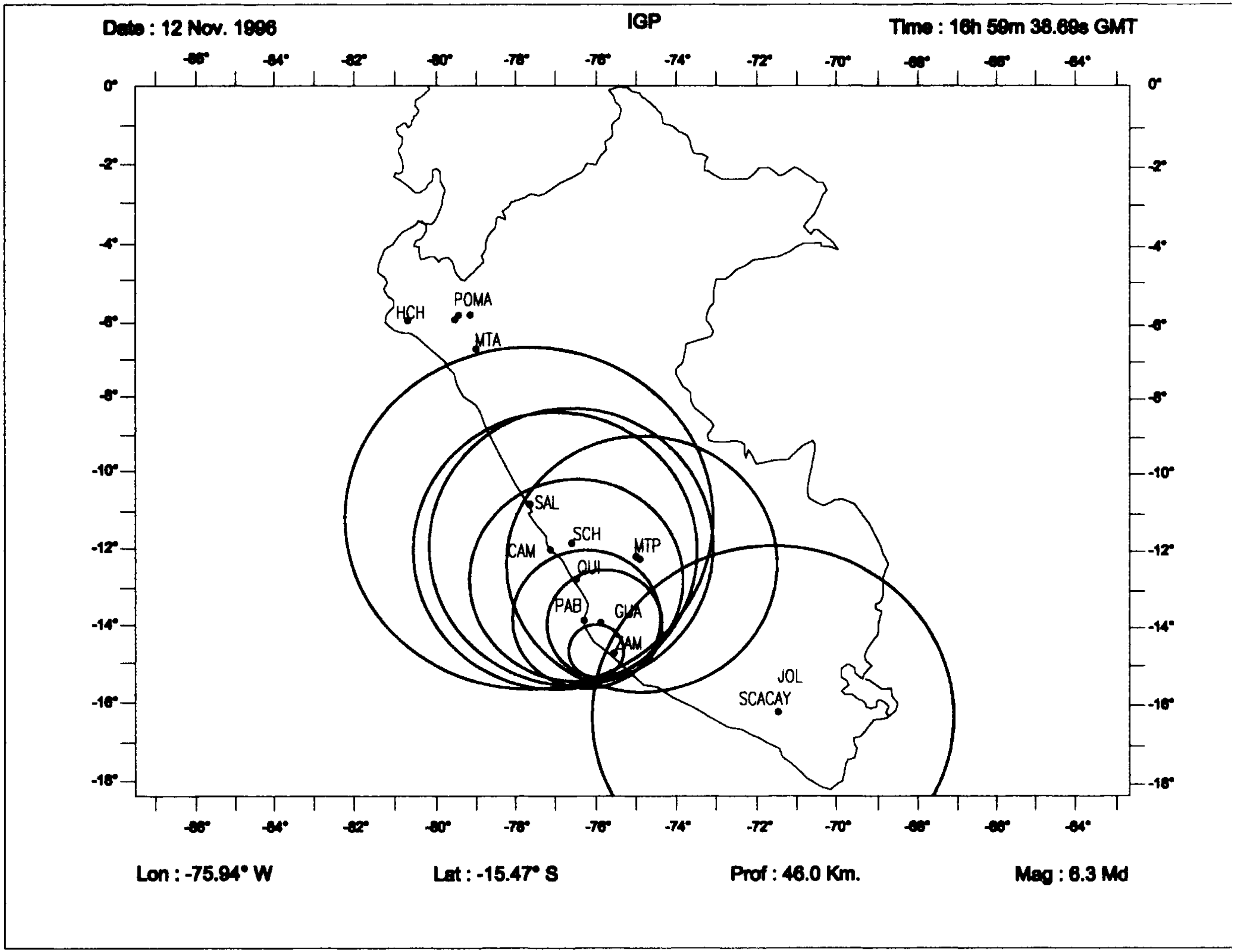

FIGURE N°1 : EPICENTER OF NOVEMBER 12,1996 NASCA EARTHQUAKE (IGP, 1997)

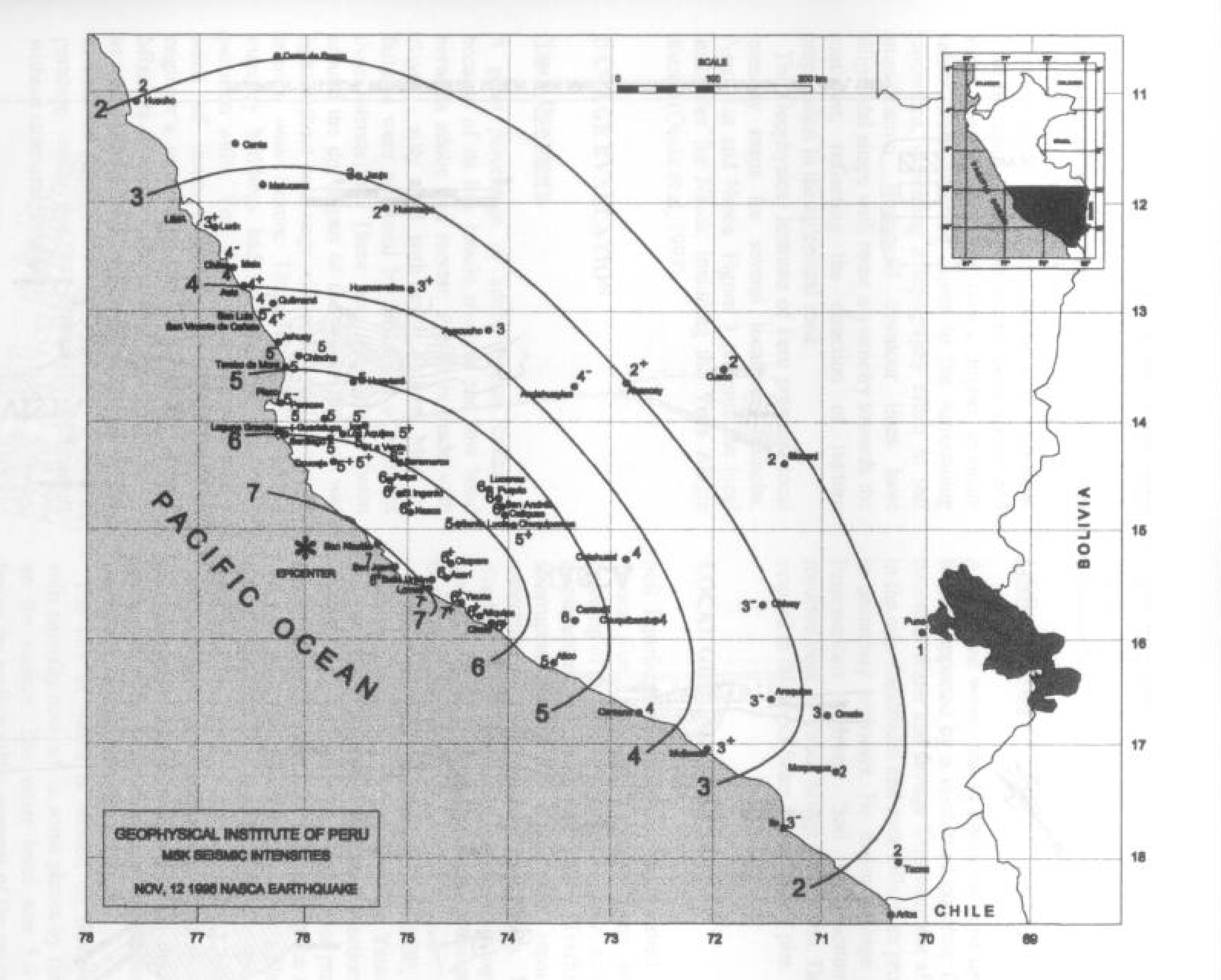

FIGURE N° 2 : ISOSEISMAL INTENSITY MAP OF NASCA NOV 12, 1996 EARTHQUAKE (IGP, 1997)

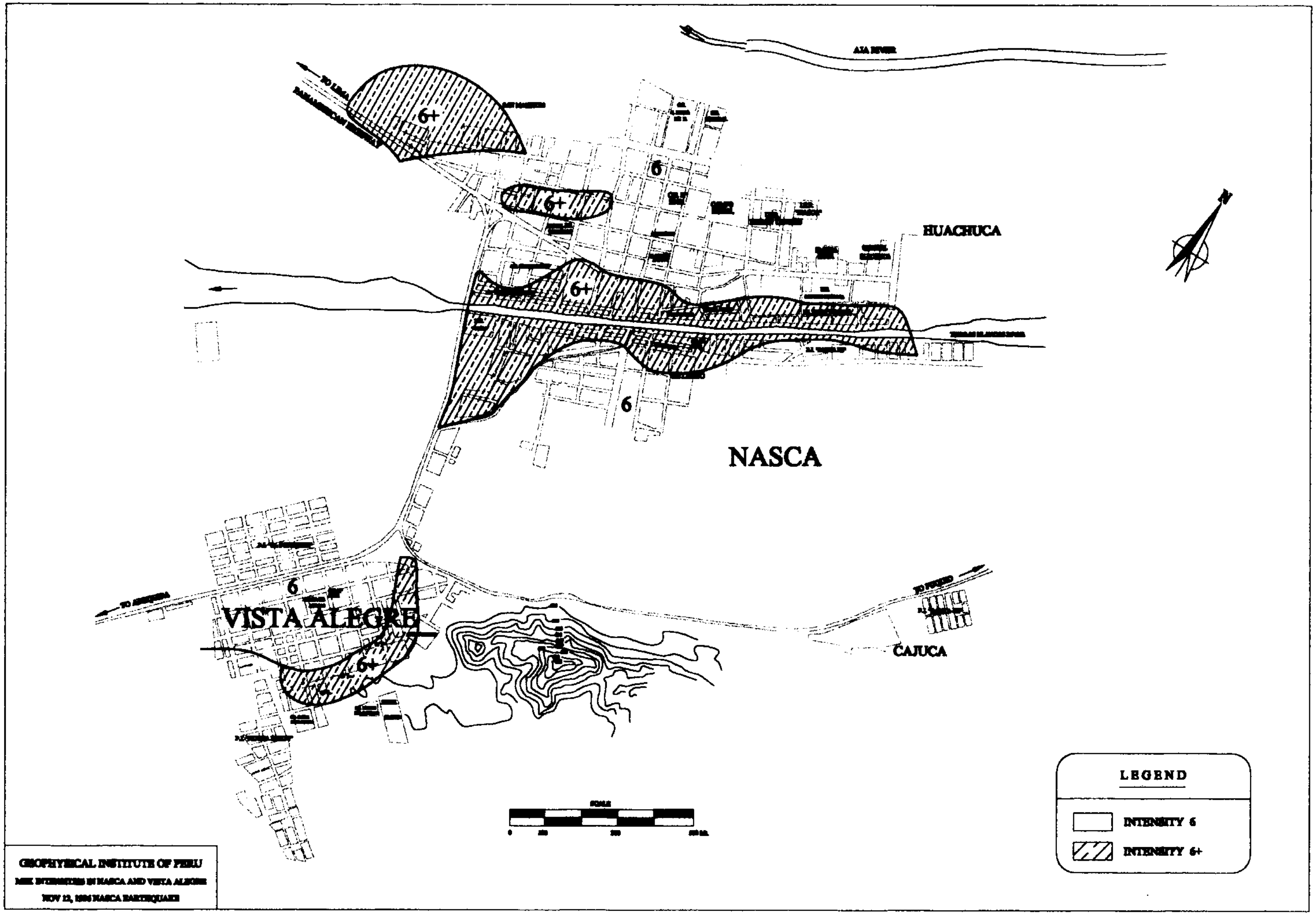

FIGURE N° 3 : LOCAL INTENSITIES OF 12 NOV 1996 NASCA EARTHQUAKE IN NASCA CITY (IGP, 1997) occurred in the estuary of the Yauca river where saturated and sandy soil deposits exists. Cracking was observed in loose deposits of sand and gravel over ground slopes.

Intensities in cities and towns were estimated from building damage. In Acari, Bella Union and Vista Alegre district of Nasca, higher intensity values were observed closer to the surrounding mountains, indicating a topography effect in soil amplification. Isoseismal countour lines have ellipsoidal shape with some asymmetry towards the southeast, reflecting the direction of rupture propagation in the epicentral zone.

The Geophysical Institute of Peru prepared local intensity maps for several localities: Chincha, Pisco, Ica and Nasca. Figure 3 presents the local intensities for Nasca, including the Vista Alegre district (Ocola et al, 1997).

DAMAGE EVALUATION

Nasca Downtown

A great percentage of adobe houses collapsed because of its low tensile strength and low bond between adobe and mortar. Adobe is made with clayey - silty sand with brittle failure. Most of failures were produced by separation of walls at their intersection. There was not a collar beam around the upper part of the walls. The roof was light without anchorage with walls. Failure was by tension with flexure. Unconfined and confined masonry buildings had light damage, mostly in partition walls. Very few had structural damage. Most of these buildings were built without engineer's supervision and without confinement. Mixtures of adobe and masonry walls were noted, as well as adobe walls with concrete roofs. Damage in concrete framed structures is related mostly to partition walls due to structural deformation, without structural damage.

Schools

During this earthquake, as in previous earthquakes, higher percentage of damage was produced in schools as compared with other types of buildings. Main reason being its architectural vulnerability to faulty construction. In recently built Fermin del Castillo and Jose Carlos Mariategui schools in Vista Alegre district, extensive structural damage was produced in concrete structures and confined masonry. Besides, important construction defects were observed. Soil conditions are good. The topography suggests soil amplification. Short column effect was notorious.

Lifeline Systems

An elevated water tank in Nasca suffered damage. It was supported by a reinforced concrete framed structure. Water and sewage lines were not affected in the city. Landslides and rock falls were produced in secondary highways. No major damage in the Panamerican highway. Soil Liquefaction was reported near of Yauca bridge foundation. Damage ocurred in the upper beam of the central pier.

LOCAL GROUND EFFECTS

Soil liquefaction occurred in the riverbed of the Yauca river. One of the river piers suffered cracking of the upper beam and columm, as well as displacement of the bridge slab. Traffic was interrupted across the bridge and repair and restoration was inmediately undertaken. In the riverbed sand volcanoes and cracking was observed. The bridge foundation consisted of caissons (Pique, 1997).

The Geophysical Institute of Peru (IGP, 1997) reported generalized liquefaction in the Yauca river estuary. Sand volcanoes and mud ejection were observed. Landslides and rock falls were produced along highways towards the highlands in the Andes.

A very important phenomena was the collapse of tailing dams due to liquefaction and flow. The dams were located in Acari, Jaqui and Chala. The collapsed dams were built by the upstream method of construction and were in operation during the earthquake. The Acari river was contaminated by one of the tailing dams that collapsed.

The city of Nasca is located on fluvio-aluvial soils partially covered in some places by fine soils on the surface. The water level was 5.0 meter below the surface at the moment of the earthquake. Vista Alegre district is to the south of Nasca and has rolling ground surrounded by mountains. For this reason soil amplification developed.

In Palpa there is silty-clay material at the surface, medium stiff with different water content. Gravel is located 5.0 m. below surface. In Acari and Bella Union gravel material is present in the ground with the exception of Old Acari where fine material exists at the surface.

In general no important ground effects were noted in the main cities affected by the earthquake.

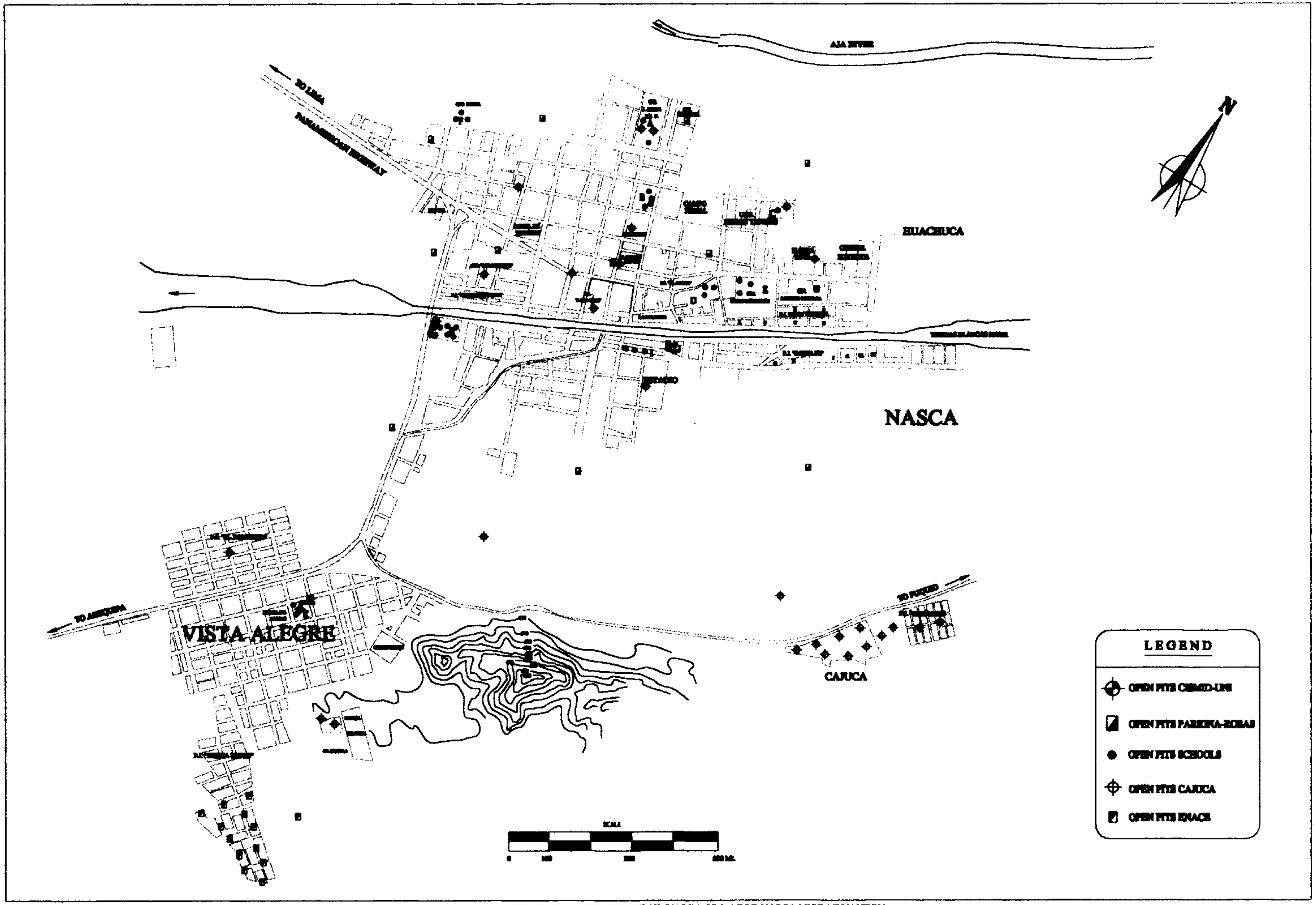

FIGURE N° 4 : SOIL EXPLORATION PROGRAM FOR NASCA MICROZONATION

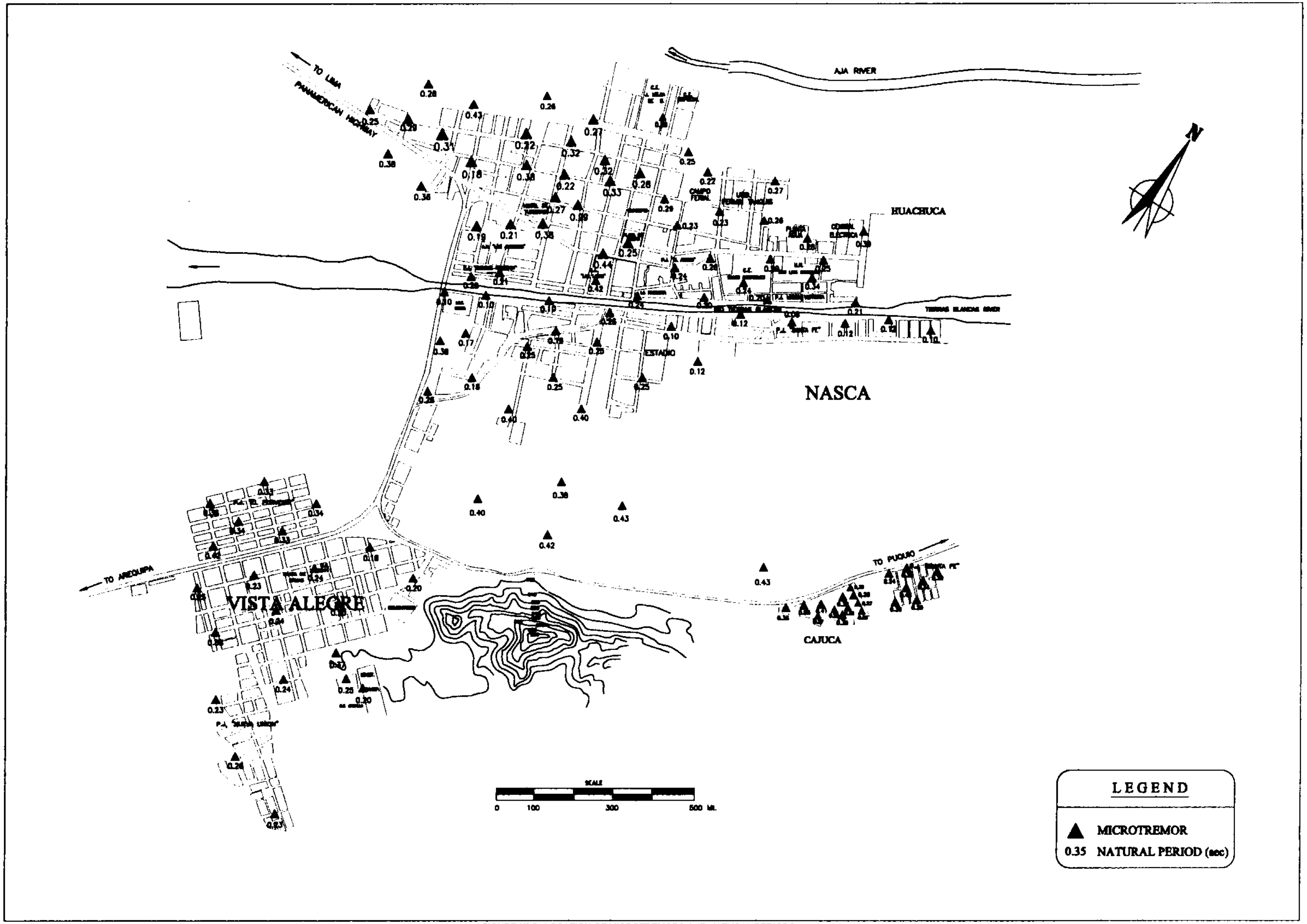

FIGURE N° 5 : LOCATION OF MICROTREMORS AND NATURAL PERIODS

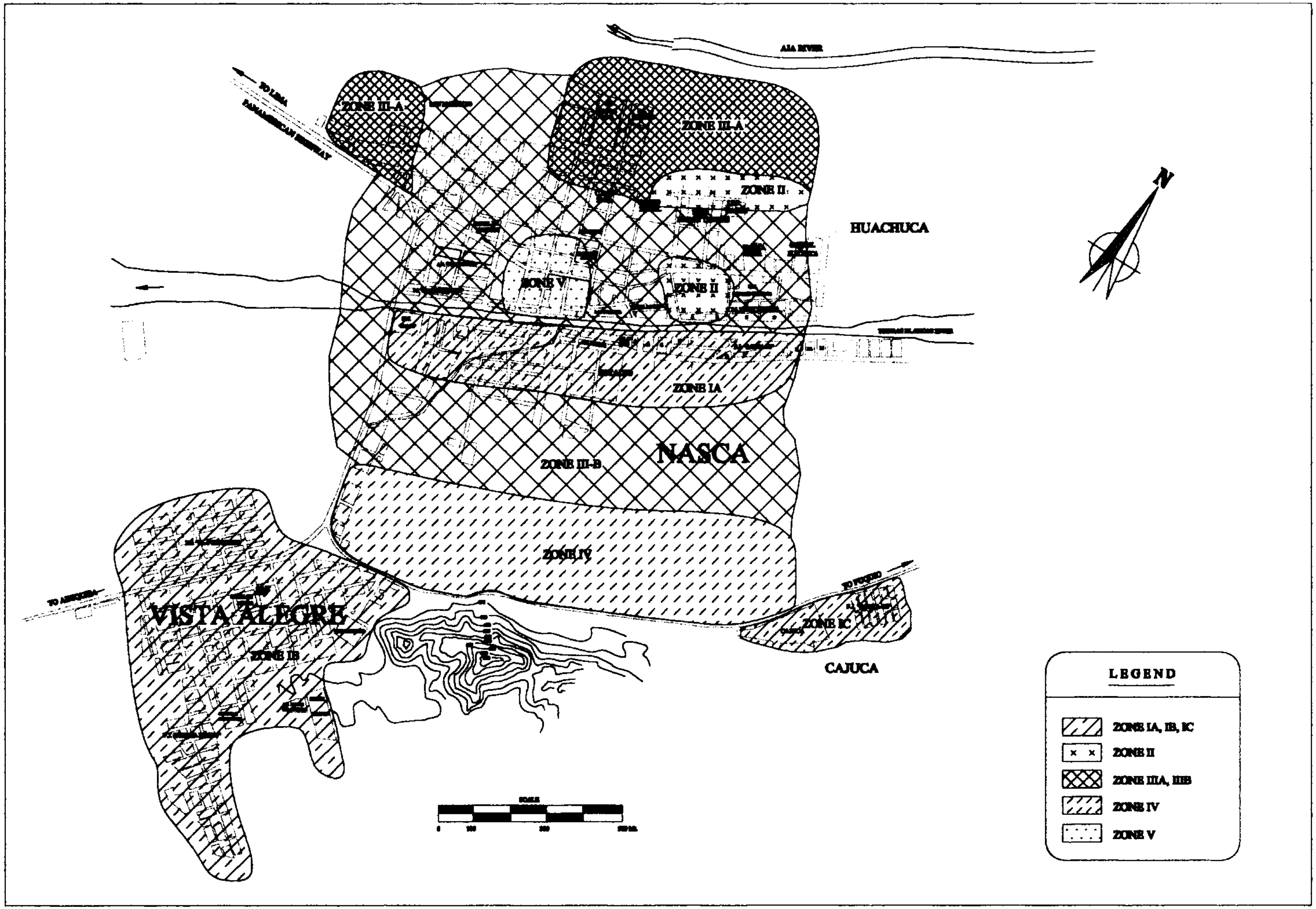

FIGURE N° 6 : SEISMIC MICROZONATION OF NASCA CITY (Vásquez and Alva-Hurtado, 1997)

SEISMIC MICROZONATION OF NASCA

To contribute with the reconstruction of Nasca, a microzonation of the city was undertaken, Available information was compiled (Pariona and Rosas, 1993, Huiman, 1996) and a soil exploration and microtremor measurement program was undertaken (Vasquez and Alva-Hurtado, 1997). A study involving microtremor and aftershocks measurements was also reviewed (Bondoux, et al, 1997).

Figure 4 present the location of open pits compiled and executed in Nasca and Vista Alegre. Because of the nature of the ground, hand made open pits up to 5.0 meters in depth were made. Figure 5 presents the locations of the microtremor measurements and their natural periods under ambient vibration.

The city was divided into five zones as presented in Figure 6.

Zone I. This zone has the best geotechnical conditions. The ground is composed of compacted gravel with boulders up to 10" in diameter. Bearing capacity is over 2 kg/cm^2 and the predominant period of soils is between 0.1 and 0.2 seconds. This zone was subdivided in 3 subzones.

Zone II. This zone is similar to zone I, with gravel down to 1.5 meters in depth. Fine material exists at the surface. Bearing capacities are from 1.5 to 2.0 kg/cm^2 and the predominant periods of soils are from 0.20 to 0.25 seconds.

Zone III. A medium thick layer of fine soils exists at the suface. Below the superficial layer, the gravel layer appears. For shallow foundations settlements are expected. It is recommended to reach the gravel layer for founding important buildings. Bearing capacities range from 1.0 to 1.5 kg/cm^2 and soil predominant period varies from 0.25 to 0.40 seconds.

Zone IV. The superficial layer consists of silty and clayey soils with thickness greater than 5.0 meter. The gravel layer is located beneath this layer. Bearing capacity of 1.0 kg/cm^2 is expected for shallow foundations. Predominant period is greater than 0.4 seconds. This zone is not developed. Soil amplification is expected because of the presence of nearby mountains.

Zone V. This is a critical zone because there is loose thick fill on the surface. This area is near Nasca downtown where adobe houses collapse was total during the earthquake. It is recommended to use this area for public recreation and parks.

CONCLUSIONS

1) Even though this earthquake had a moderate intensity, 75% of adobe buildings suffered severe damage or collapse. Main damages in adobe buildings are related to poor unions between walls and weak roof diaphragms, extended cracking along adobe joints in walls and overturning of fences and main walls.

2) Masonry buildings had light damage, mostly in partition walls.

3) Concrete framed structures presented non-structural damage. A special case was the recently built state schools where short columns developed because of large structure deformations and faulty construction

4) Future development of Nasca is recommended towards zones I and II, where the ground is composed of compact sandy gravel. Flood protection structures along the river banks should be provided. Zone III has second priority because the gravel layer is deeper.

5) Zone IV and V are critical because the gravel is below 5.0 meters. Zone IV is close to the nearby mountains and could develop soil amplification. Zone V has loose fill at the surface providing weak foundations.

6) Based upon damage produced by the earthquake some modifications to the peruvian earthquake code were proposed.

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