Reconstruction of Ica, Pisco, Chincha and Cañete, Peru, Based on Updated Hazard Maps

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ABSTRACT

In view of the growing unplanned urban development taking place, which makes the cities in developing countries inefficient, hostile and risky, we propose a desirable model city - one we would be happy to live in and hand down to future generations: a sustainable city (SC) - safe, orderly, healthy, attractive, efficient, environment-friendly, appreciative of its cultural-historic heritage and therefore, governable and competitive.

At the time that the Ica Region or Pisco earthquake occurred on August 15, 2007, the Sustainable Cities Program - 1st Stage (SCP-1S) - focusing on its first attribute, its physical safety - had already completed the hazard maps of 130 Peruvian cities and towns, with 6.4 million inhabitants, including 16 cities located in the Ica Region macroseismic area. The program was initiated in 1998.

Quick field surveys made soon after the event have shown that the hazard maps of Ica, Chincha, Pisco and Cañete had good correlation with the actual seismic damage degree and its geographic distribution. It was therefore decided to expand and densify those cities, based on their updated hazard maps. There are validating hazard maps of 26 cities and towns which are being applied in their urban development plan.

If urban occupation is made based on hazard maps and uses Peruvian earthquake resistant technologies developed over the past 10 years for brick and concrete block masonry housing and reinforced concrete buildings, it is expected the earthquake damage will be less than 5% of its value and the residents will be adequately protected.

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INTRODUCTION

In view of the growing unplanned urban development taking place, which makes the cities in developing countries inefficient, hostile and risky, we propose a desirable model city: one we would be happy to live in and hand down to future generations: a sustainable city (SC). (Kuroiwa, 2004)

A sustainable city (SC) is defined as one which is safe, orderly, healthy, culturally and physically attractive, a city that is efficient in its functioning and development does not have a negative impact on the environment or on its cultural/historic heritage, and, as a result of all this, is governable. The final goal is to achieve a competitive city, capable of producing goods and services efficiently, which will attract investment to create new job opportunities, thereby making it possible to raise the standard of living of its inhabitants.

Evidently, all these attributes can materialize only in the long term, but it is possible to carry out priority actions in the short term; one of which is to protect life and health, every individual´s most precious possession. Obtaining other attributes becomes, in the long term, the objective of local, regional, and national governments; and their objectives in this context will serve them as guidelines in their decision-making and short-term activities. In this way, there will be no squandering of the nearly always scanty funds, and a clear line of action will have been defined, to put an end to the series of tentative advances and disappointed retreats that have caused so many delays in the past. A proposal was made in June 2008, to the Peruvian Association of Municipalities (AMPE) during its Annual National Assembly, attended by 300 mayors from all over the country, to use the Sustainable City Program as their "route map" from 2008 to 2021, the bicentenary of Peru's Independence.

Guidelines for developing a sustainable city, including examples, microzonation methods and techniques, the importance of lifeline services and essential facilities for a safe urban life, where and how to locate them, and what mitigation measures may be taken to protect them are included in chapter 2: *Sustainable cities – Agenda for the 21st century*, pages 34-99, (Kuroiwa, 2004)

However, in order for this paper to be self-contained, and how lifelines be strategically planned to reduce disasters, a few paragraphs are included. The hazard map is based on the traditional microzonation methods and techniques with a multihazard approach. A typical team has the following specialities: geology, soil mechanics, hydrology/hydraulics, environment, GIS. Usually the coordinator or team leader is an urban planner or architect. Such professionals are closer to the population's social needs than engineers, and better able to produce a friendly document for the next user. When necessary, other specialists are added. For example, a specialist on tsunamis for Pisco and San Andrés, which are located on the sea shore.

The present city plus its foreseen expansion is the area to be investigated, taking into consideration the effects of intense or slow-onset natural threats and man-made menaces. For each threat, the investigated area is divided into: very high, high, medium and low hazard sectors. The envelope of all existing menaces, presented in a friendly way to the urban planners, local communities and authorities, is the hazard map.

There follows a summary of Table 2.1 (p.41, Kuroiwa, 2004) where the hazard degree, the sector's characteristics, examples, restrictions and recommendations for land-use planning for disaster reduction are included. Very-high-hazard sectors are not permitted for urban uses. The forces of nature are so strong there that man-made constructions cannot withstand them, and if the phenomenon occurs, losses reach 100%. For example, sectors threatened by landslides, avalanches and sudden flows of mud and rocks (presented in red color)

Hazardous (orange). The threat is high but effective damage reduction measures can be taken at reasonable cost. For example, strips of land adjacent to very-high-hazard sectors where high seismic acceleration is expected, are inundated with no significant erosive forces, but the sector remains under water for several days. The site needs to be investigated by an experienced specialist. Recommended for low-density urban use; however, adobe housing is not permitted, because damage is usually total in this type of material.

Medium hazard degree (yellow). Moderate natural and man-made threats. Suitable for urban use. Usual geotechnical studies are required.

Low hazard (green) with low amplification of seismic waves, and with very remote possibility of intense natural phenomena or gradual soil failure. This sector is ideal for high density urban use, and the location of essential facilities in cases of disaster, such as hospitals, schools, police and fire stations.

Hazard maps are also very useful for the overall planning of lifelines: mains pipes for domestic water, key roads, electrical transformers, etc., should be strategically located, using the hazard maps as an effective tool. For example, in an area where high seismic acceleration is expected, as well as a great deal of soil deformation (O'Rourke M.J. & Liu, X. 1999), pipe design by blocks can be applied, enclosing and isolating with valves the area of deformable soils. Up to the present, urban fires have not been a critical issue in developing countries following earthquakes, as they have been in San Francisco, 1900; Tokyo, 1923; and Kobe 1995. However as the standard of living is improving, it means more electrical equipment, furniture and curtains to be burned, so in a not-distant future, fire may become a critical problem. A proposal was made, using the lessons learnt from the Kobe, 1995 earthquake, where railroads and wide avenues stopped the fire from spreading. These infrastructures, combined with natural barriers such as rivers and naked hills like those existing in Peru's coastal strip, may form continuous barriers to have fire-isolated sectors in important future cities. But this should be done well in advance, at the planning stage for the urban occupation of vacant extensive territory (Kuroiwa, 2005).

BACKGROUND: THREE DISASTERS BETWEEN 1997 AND 2007, THREE OPPORTUNITIES.

When the Ica Region earthquake (Mw 8.0, USGS) occurred on August 15, 2007, the hazard maps of 16 cities and towns located in the macroseismic area had already been developed in 2001-2002 as part of the Sustainable Cities Program - First Step (SCP-1S). After El Niño 1997-1998, when there was the need to reconstruct Peru's northwestern cities and towns devastated by flooding, landslides and erosion, the author proposed – to the then Prime Minister of Peru and at the same time chairman of the El Niño Reconstruction Committee (CEREN) – that the severely affected cities and towns be reconstructed applying the Sustainable Cities Program, focusing on its first attribute: physical safety (SCP-1S). A proposal to manage the SCP-1S ad-honorem was presented in November 1998, and it was immediately accepted by the then Prime Minister. The UNDP, which was already supporting CEREN, during the emergency and rehabilitation period of the El Niño affected area, continued to do so during the implementation of SCP-1S.

The best argument to convince the central government and local authorities to reconstruct the main affected cities based on their hazard maps was the fact that the inundation maps of El Niño 1997-1998 were practically carbon copies of those of El Niño 1982-1983.

Early in 2001, the SCP-1S was transferred from CEREN to INDECI (Peru's National Institute of Civil Defense). On June 23, 2001, an earthquake of Mw 8,4 (USGS) struck the southwestern region of Peru. The author was requested by UNDP/Peru to investigate the effects of that earthquake. The effects were compared with the results of the Regional Seismic Scenario (RSS), which had been developed under the framework of the Disaster Mitigation Program in Peru (DMPP) 1992 - 1995, (Kuroiwa, 2002). The UN Department of Humanitarian Affairs (UNDHA/Geneva) and INDECI were in charge of DMPP 1992-1995 and it was funded by the Canadian International Development Agency (CIDA).

The RSS 1992-1995 and the macroseismic area of the June 2001 earthquake overlapped some 90% in the Arequipa, Moquegua and Tacna regions; the exception was the southwestern side of Ayacucho region. The worst damage in the capital cities of the Arequipa, Moquegua and Tacna regions occurred in 2001 where the RSS 1992-1995 indicated, namely: in Arequipa in its lower sector where a hill dams the underground water of the Chili river, and its level is close to the ground surface; in Moquegua, on an unstable slope; and in Tacna on natural and man-made recently filled soil. In those places concrete-block or brick-masonry housing and reinforced concrete buildings collapsed or suffered severe damage; and in Moquegua, the destruction of adobe housing was total. Once again, the natural site characteristics – soil, geology and topography – showed strong influence on the seismic intensity and on the degree of damage and its geographic distribution.

So the Head of Peru's Civil Defense (INDECI), decided to expand the SCP-1S all over the country, from NW Peru affected by the 1997-1998 El Niño, and from the SW struck by the 2001 earthquake. Up to early July 2008, more than 130 Peruvian cities and towns with 6.4 million inhabitants have hazard maps already drawn up and available (Table 1); most of them already have a land-use plan for disaster reduction, and each one has 10 to 15 hazard mitigation project profiles. In addition, under the Ecuador-Peru Binational Program, the SCP-1S has been applied to three Ecuadorian cities and towns, close to the border with Peru. The Organization of American States (OAS) funded this project.

Having compared the effects of the August 15, 2007 Ica Region earthquake – systematically investigated for almost half a year, starting two days after the earthquake – with the hazard maps developed by SCP-1S INDECI/UNDP in 2001-2002 of Ica, Pisco, Chincha and Cañete, the capital cities of the provinces of the same name, the local and regional governments of the affected communities and the central government made the consensual decision to use the hazard maps of the main affected cities in their reconstruction, in view of the fact that the 2001-2002 hazard maps were in good agreement with the effects of the 2007 earthquake. Work therefore began on updating the hazard maps of the main affected cities one month after the earthquake.

VALIDATION OF THE HAZARD MAPS OF ICA, PISCO, CHINCHA AND CAÑETE

Once the unanimous decision had been made to apply hazard maps in the urban development plans of the main cities affected by the earthquake, the strategy to obtain the necessary data was drawn up as follows:

a. Reviewing and updating the 2001-2002 hazard maps, using also the advantage that the damage and its geographic distribution were there in the large full-scale laboratory i.e. the macroseismic area.
b. Adding those towns that suffered severe damage during the 2007 event, and which had not been included in the previous studies.
c. Intensifying the communication and coordination with local communities and authorities in workshops, lectures, field surveys, and small group community meetings, to capture their vision of their cities for future generations, and let them know the dramatic reduction there will be in loss of lives and properties, if hazard maps and disaster mitigation measures are included in their socio-economic development projects.

Table 1

Sustainable Cities Program INDECI/UNDP, 1998-2008. Results

1 TUMBES ✓	Tumbes (88.4*), Aguas Verdes (10.3), Zarumilla, Papayal.
2 PIURA ✓	Talara (97.8), Sullana (160.0), Paita (57.4), Sechura (16.7), Chulucanas (38.9), Huancabamba (6.8), Ayabaca (6.0), Castilla (108.7), Catacaos (50.4), Piura, Suyo.
3 LAMBAYEQUE ✓	Chiclayo (535.4), San José (7.6), Pimentel (14.2), Eten (11.9), Picsi (4.8), Puerto Eten (2.5), Túcume (6.7) Monsefú (24.6), Reque (9.7), Lambayeque (40.9), Ferreñafe (32.3), Mórrope (4.7), Santa Rosa (13.0)
4 LA LIBERTAD	Trujillo.
5 ANCASH	Chimbote (313.2), Huarmey (17.1), Carhuaz (7.2), Recuay (3.1), Cátac (2.6), Ticapampa (2.5), Huaraz (93.3), Caraz (11.3), Yungay (5.9), Ranrahirca (0.8)
6 LIMA ✓	Cañete (40.8), Cerro Azul (6.6), Nuevo Imperial (14.5), San Luís (11.7), Imperial (35.7), Quilmaná (12.5), Lunahuaná (3.8), San Antonio (3.4), Asia (14.1), Mala (22.8), Chosica, Santa Eulalia, Ricardo Palma (3.9), Matucana (4.4), Chancay (38.0), Huacho, Supe Puerto, Paramonga, Barranca.
7 ICA ✓	Ica (283.1), San José de los Molinos (6.0), La Tinguiña (31.6), Palpa (8.2), Parcona (49.7), Nasca (35.5), Subtanjalla (16.2), Pueblo Nuevo (1.5), Tate (2.0), Guadalupe (8.3), Santiago (5.7), Los Aquijes (2.5), San Juan Bautista (0.9), Pisco (64.6), Chincha (151.9), Chincha Alta (49.8), Alto Laran (6.8), Grocio Prado (16.2), Pueblo Nuevo (36.8), Sunampe (17.6).
8 AREQUIPA ✓	Arequipa (1,073.0), Camaná (51.4), Cocachacra, Caravelí, Punta de Bombón, Dean Valdivia, Aplao, Chuquibamba, Corire, Cosos, La Real, Huancarqui, Lara, Viraco, Pampacolca, Lluta, Machaguay, Huanca, Callalli, Sibayo.
9 MOQUEGUA	Omate, Puquina, Moquegua, Ilo.
10 TACNA ✓	Tacna, Locumba (1.1), Tarata (4.7), Candarave (2.3)
11 AYACUCHO ✓	Ayacucho (107.4), Huanta.
12 CUSCO ✓	Cusco, Ollantaytambo, Urubamba, Calca (10.5), Písac, Sicuani.
13 MADRE DE DIOS	Puerto Maldonado (35.2), Iberia, Iñapari.
14 CAJAMARCA ✓	Cajamarca (98.2), Baños del Inca (5.3), Jaén (54.7)
15 SAN MARTÍN ✓	Moyobamba (37.3), Tarapoto, Juanjuí (18.0), Bellavista (8.2), San Hilarión (3.0), Lamas (11.3), Rioja (19.0), Nueva Cajamarca (15.8), Yuracyacu (3.8)
16 APURIMAC	Abancay.
17 JUNIN	San Ramón.

* *Thousands of inhabitants*

From 11/1998 to 06/2008, 133 cities and towns with 6.4 million inhabitants have been investigated. Agreements have been signed with participating local national universities: ✓
In 10 years some 80 consultants have been trained on the job.

Points a) and b) were manly implemented by local consultants of the INDECI/UNDP SCP-1S – most of them were professors from the National University of Ica – managed by its three-member working group, which included the author. In all, the hazard maps of 26 cities and towns were updated or added to the original list of 16 completed in 2001-2002, and they are being applied at present.

Point c) was executed mostly by a team from the different agencies of the UN System, coordinated by UNDP/Peru, through its temporary offices in Ica, Pisco and Chincha.

In the province of Ica, six new towns were added to the investigation; and in Chincha, four. The validation studies were made from mid-September 2007 to mid-May 2008. Except for the validation of Pisco, which was mainly funded by the Peruvian Government, all the other investigations were funded by the Department for International Development of the United Kingdom (DFID, UK.) benefiting 26 cities and towns with a total population of 940,300 inhabitants.

In this paper we include, as examples only, the 2001-2002 SCP-1S INDECI/UNDP hazard map of Pisco (Fig. 1), as well as its valid version developed from September to December 2007 (Fig. 2). A few pictures of damage in Pisco and Tambo de Mora are also included. This damage occurred in sectors that had been predicted in 2001-2001 to be very high and high-hazard areas threatened by soil liquefaction and tsunamis, as in fact happened during the August 15, 2007 earthquake.

The Manual for the Development of Sustainable Cities (Kuroiwa & Salas 2008, pp 80-82) includes the validated hazard maps of Ica, Chincha and Cañete. In Annex 1 of that Manual, a short description of microzonation methods and techniques is included, as well as key maps of the six new towns of the province of Ica, to show the process of microzonation investigation.

The seismic microzonation studies of Pisco, Huaytara and San Luis de Cañete were funded by the Inter-American Development Bank (IADB) and those of Tambo de Mora and Chincha Baja by the World Bank (WB) and carried out by the Japan-Peru Center for Earthquake Engineering Research and Disaster Mitigation - CISMID of the Civil Engineering Department, National University of Engineering (FIC/UNI) Lima, Peru.

The microzonation studies of Pisco were first made in 2001-2002 and they were reviewed and updated by the SCP-1S Working Group in September-December 2007. The Pisco area was also investigated by CISMID FIC/UNI. It is the only case where the studied area overlapped.

The author was requested to compare the validated SCP-1S with the CISMID microzonation studies, which turned out to be favorable. The agreement was approximately 85%. The very-high-hazard sector coincided the best. This is a strip parallel to the coastline where soil liquefaction and tsunami are the main natural threats. The sector to the southeast of Pisco is a medium-hazard one. It had been selected for the city expansion and population densification. In that sector there is a difference. While in the validated SCP-1S hazard map there is a transition strip between the medium and high hazard parts, in the CISMID hazard map, there is no transition zone between the medium and very high hazard areas.

In downtown Pisco, the CISMID studies identified small spots of very high hazard within the high-hazard sector, which had not been detected by the SCP investigation.

On the SCP hazard map the boundaries between sectors of different hazard levels run along the axes of avenues and streets because of the technical legal implication of the municipal ordinances, while the CISMID solutions make use of engineering results and boundaries. On June 3, 2008, the mayor of Pisco signed the Municipal Ordinance approving the validated SCP-1S hazard map. Together with the team in charge of urban planning for Pisco, the author is making progress with a solution for all the problems of the very-high-hazard sectors.

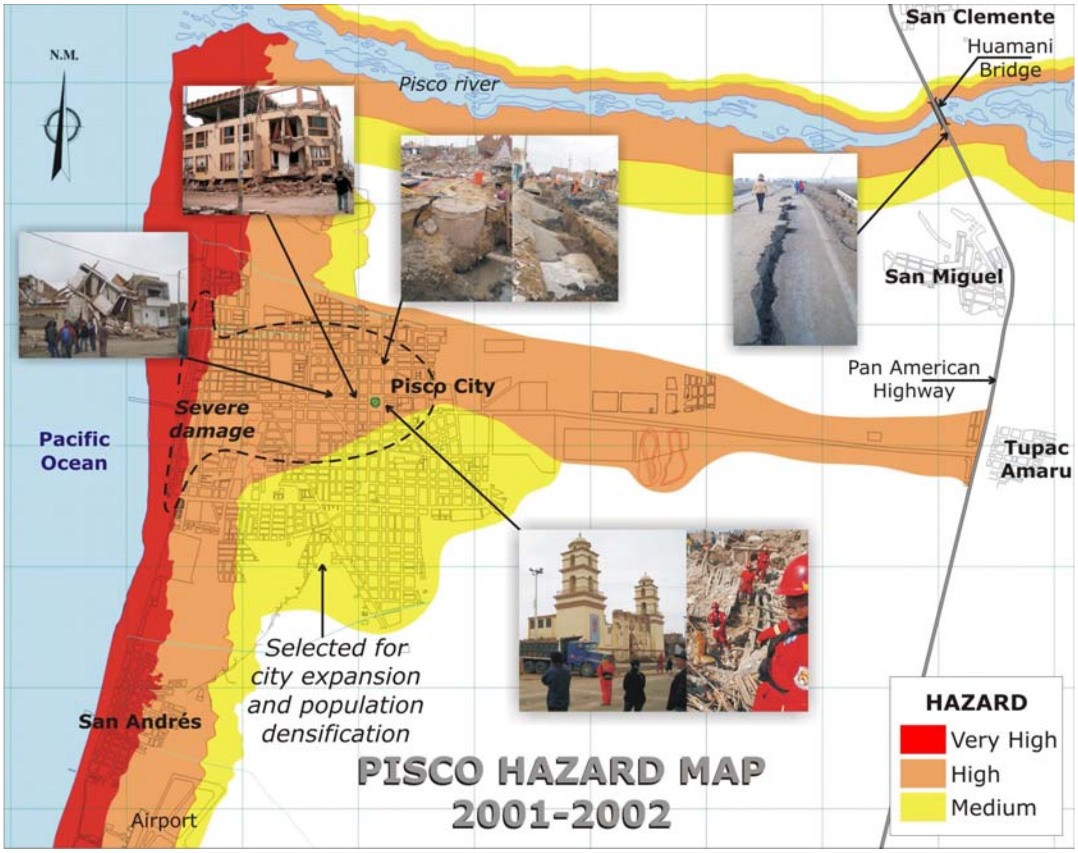
San Clemente
Huamani Bridge
N.M.
Pisco river
San Miguel
Pan American Highway
Pisco City
Severe damage
Pacific Ocean
Tupac Amaru
Selected for city expansion and population densification
San Andrés
Airport
PISCO HAZARD MAP 2001-2002
HAZARD
Very High
High
Medium

Fig. 1

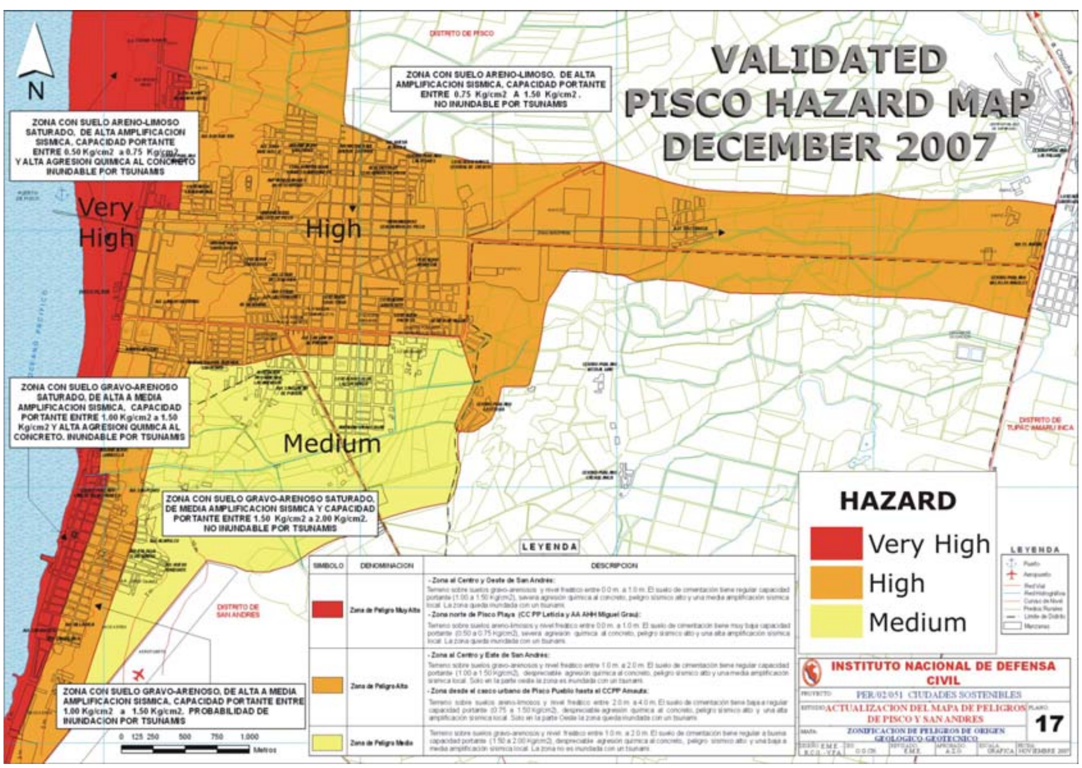
VALIDATED PISCO HAZARD MAP DECEMBER 2007
N
DISTRITO DE PISCO
ZONA CON SUELO ARENO-LIMOSO SATURADO, DE ALTA AMPLIFICACION SISMICA, CAPACIDAD PORTANTE ENTRE 0.50 Kg/cm2 a 0.75 Kg/cm2 Y ALTA AGRESION QUIMICA AL CONCRETO INUNDABLE POR TSUNAMIS
ZONA CON SUELO ARENO-LIMOSO, DE ALTA AMPLIFICACION SISMICA, CAPACIDAD PORTANTE ENTRE 0.75 Kg/cm2 A 1.50 Kg/cm2. NO INUNDABLE POR TSUNAMIS
Very High
High
ZONA CON SUELO GRAVO-ARENOSO SATURADO, DE ALTA A MEDIA AMPLIFICACION SISMICA, CAPACIDAD PORTANTE ENTRE 1.00 Kg/cm2 a 1.50 Kg/cm2 Y ALTA AGRESION QUIMICA AL CONCRETO. INUNDABLE POR TSUNAMIS
Medium
ZONA CON SUELO GRAVO-ARENOSO SATURADO, DE MEDIA AMPLIFICACION SISMICA Y CAPACIDAD PORTANTE ENTRE 1.50 Kg/cm2 a 2.00 Kg/cm2. NO INUNDABLE POR TSUNAMIS
DISTRITO DE SAN ANDRES
ZONA CON SUELO GRAVO-ARENOSO, DE ALTA A MEDIA AMPLIFICACION SISMICA, CAPACIDAD PORTANTE ENTRE 1.00 Kg/cm2 a 1.50 Kg/cm2. PROBABILIDAD DE INUNDACION POR TSUNAMIS
0 125 250 500 750 1.000
Metros
LEYENDA
SIMBOLO
DENOMINACION
DESCRIPCION
Zona de Peligro Muy Alto
Zona de Peligro Alto
Zona de Peligro Medio
HAZARD
Very High
High
Medium
INSTITUTO NACIONAL DE DEFENSA CIVIL
17

Fig. 2

Soil Liquefaction in Tambo de Mora

Settlement of some 2.6 feet (0.8 m)

Lateral spread. The right wall has moved to the right and towards the reader, "opening a door".

House settlement and floor cracks

Sand volcano

LESSONS LEARNT FROM DISASTERS THAT OCCURRED IN PERU FROM 1997 TO 2007.

Lessons learnt on lifeline systems and the importance of essential facilities in the event of disasters will be briefly analyzed based on the lesson learnt from the El Niño 1997-1998 and the Arequipa 2001 and Ica 2007 earthquakes, focusing on the effects of those events on roads and the domestic water supply. They were the facilities that suffered the most in these events. But this is not only a Peruvian problem. For example, failure of an elevated expressway caused traffic chaos in northern California in 1989, during the Loma Prieta earthquake. The collapse of a single span of the bridge connecting San Francisco and Oakland forced the users to cross by other bridges located many miles to the south. The fact that the elevated expressway had been built with codes that are currently obsolete, coupled with the soft soil around the San Francisco bay, gave rise to these failures. In Kobe, during the 1995 earthquake, the overturning of several spans of the elevated expressway caused serious transportation problems for months.

Many stretches of the Pan-American Highway were destroyed along the northern coast of Peru during the 1982-1983 and 1997-1998 El Niño phenomena, particularly where the highway crossed perpendicularly dry gullies and river beds that had, after many years, become filled with fast-moving water. In 1998 and 1999 studies were made of the floods caused by the 1997-1998 El Niño over nearly 625 miles (1000 km.) of the North Pan-American Highway from Huarmey up to the border with Ecuador. The project was financed by the Maintenance Service of the Peruvian Ministry of Transport and Communications (MTC) and developed at CISMID

FIC/UNI, and four professional civil engineering theses were written focusing on different stretches of the highway, taking approximately 156 miles (250 km.) each. One of the main types of failures that occurred in the highway was damage from erosion at points where the Pan-American Highway is crossed perpendicularly by water courses. This occurred particularly at bridges, where the abutments and the last section of the bridges failed due to erosion. The total span of the bridge proved too short for the new width of the water course. In the public competitive bidding for the reconstruction of the bridges that failed during El Niño 1982-1983, the contracts were won by the firms that offered the lowest proposals, which was apparently the correct thing to do, but on reviewing the winning technical-financial proposals, it was determined that the clear spans of the bridges had been shortened, replacing them with fill at both ends, thereby reducing the width of the river´s flow. Just 15 years later, El Niño 1997-1998 destroyed those bridges, bringing about a major deterioration in the development of the northwest region of Peru.

On the other hand, the Saman bridge, whose failure had isolated large areas of that region in 1983, and the canal-freeway of Sullana, which were constructed not in the private interests of some consultants and contractors, but strictly in keeping with the lessons taught by nature in 1983 – the width of the Saman River and the flow on the gully in Sullana, respectively – behaved satisfactorily during the El Niño phenomenon of 1997-1998.

Elements responsible for increasing the damage include trees and branches caught between the pillars of bridges reducing the water carrying capacity, so that nearby areas became flooded. A bridge connecting two important sectors of Piura, capital city of the region with the same name collapsed because the river eroded it is intermediate supports. The solution was a single span bridge.

Another typical type of damage was regressive erosion. Along the Pan-American Highway, which runs from south to north, water pounded and remained stagnant to the east side of the platform, which is the direction from which the water flowed from the buttresses of the western Andes range to the Pacific ocean. When the water level rose, the water started to run from east to west, eroding the highway. First it lifted the asphalt sheet and then the base of the platform, eroded from back to front rendering the road impassable. In some sections, the failed part (perforation) took the shape of the gully that had eroded it. This is illustrated in photos and figures on pages 474 and 475, Kuroiwa, 2004.

The Pan-American Highway crosses the upper part of the city of Sullana where a gully was dammed by the highway platform some 15 feet (4.5m high). Tens of thousands of cubic feet of water were dammed by the highway during El Niño 1992-1993 and “dam-break” occurred. Waves of water ran down the slope along the axis of a very open “V” shape. There 3- to 4-blocks wide of buildings, water main pipes and paved street and sidewalks were first impacted by the waves of water and then eroded. Some 80 people lost their lives due to this event. In the mid-1980s, a bridge was built in place of the highway platform and a canal freeway was constructed along the way indicated by the nature.

During the 1997-1998 El Niño, as intense as the 1982-1983 events, the water ran freely and no damage was inflicted on the city of Sullana. Illustrations of the Sullana case 1982-1983 and 1997-1998 are included on p.43, Kuroiwa, 2004. This is a typical example of a disaster mitigation project, which, together with the city’s hazard map and land use plan is part of the set of documents handed by the SCP-1S to the cities’ mayors to reduce disasters in their jurisdiction.

Damage to roads caused by the Arequipa 2001 and Ica 2007 earthquakes had practically the same causes. Damage to the Pan-American Highway and other paved main roads in Peru’s southwestern region caused by the 2001 Arequipa earthquake was clearly influenced by the site characteristics. In fact, damage occurred only at intersections with narrow irrigated valleys where the soil is humid all year around, and at the unconfined sides of thick filled platforms. (Kuroiwa, 2002)

During the 2007 Ica Region earthquake the worst damage along the Pan-American Highway occurred where the soil is wet, as in km 190, and one side of the platform is unconfined for more than 13 feet (4.0m) high. Under this portion runs the Chillon gully that usually carries water only from January to March, but the humidity is maintained all the year round. There the embankment collapsed and shear failure of the three-cell concrete box culvert occurred (O´Connor et al, 2007)

Visible cracks were observed on the highway pavement from km 182 to km 188. The validated Chincha hazard map Kuroiwa & Salas, 2008 showed that an irrigation-by-inundation project is located in the upper plain hundreds of feet east of the Pan American Highway, from where water is infiltrated. There was also damage, with cracks in the pavements as far as 95 miles (150 km.) from the earthquake epicenter, in Villa, Metropolitan Lima, where it crosses a muddy sector. A comprehensive report of damage to roads and bridges in the macroseismic area of the August 15, 2007, earthquake was released on December 10, 2007 by J. O´Connor, L. Mesa and M. Nykamp, and a number of pictures of the damage sustained are also included in their report.

CONCLUDING REMARKS

The Ica Region 2007 earthquake has shown once again that the local conditions: soil characteristics, geology and topography, have a strong influence on the degree of damage and its geographic distribution. Fine, very humid soil (soft soil) produces large seismic wave amplification, as observed by the author during a dozen earthquakes in the Americas over the past 40 years. This conclusion agreed well with those of Idriss I.M. (1991) and Seed R. B et al (2001). In water-saturated fine sand and silt, liquefaction may occur. In recent land fills and unstable slopes the seismic hazard is high. These local characteristics may be investigated in advance to developed hazard maps.

With the effective application of hazard maps in urban development planning and using earthquake-resistant techniques developed in Peru during the last 10 years for brick and concrete-block masonry housing and reinforced-concrete buildings, damage may be reduced to less than 5% of the construction value and the residents protected (Kuroiwa et al, 2008).

At the time that this paper is being closed, a meeting with consultants of the Social Capital Group, in charge of the Chincha urban plan, confirmed that the validated hazard map of Chincha concluded in April 2008 is being properly applied.

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