NEW APPROACH TO REDUCING THE RISK OF NATURAL DISASTERS

Julio Kuroiwa[1]

[1] *Professor Emeritus, National University of Engineering & CTA Reconstruction Programme / Sustainable Cities UNDP / Peru. Av. Del Parque Sur 442, Lima 27. Peru*
E-mails: jkuroiwah@infonegocio.net.pe, editnsg@speedy.com.pe

ABSTRACT

Reducing the risk of disaster -in structural engineering terms- generally consists of reducing the constructions' vulnerability, but the resulting buildings are not necessarily safe. For example, 3000 reinforced concrete and steel buildings collapsed or were severely damaged in the Lake Zone in Mexico City, during the 1985 earthquake, and severe damage was inflicted on wooden apartment buildings at the Marina district in San Francisco, CA, during the Loma Prieta 1989 earthquake. In both cases the natural site characteristics were very unfavorable. So a different approach is proposed, giving priority importance in developing urban plans for disaster reduction based on hazard maps, according to earth sciences and engineering investigations, but without disregarding the latest technology on earthquake resistant design. This approach is being applied in the reconstruction of the largest cities affected by the Peru August 15, 2007 earthquake. It is expected that the damage will be reduced to less than 5% of the construction value and the residents will be adequately protected. Special application is made for school buildings. The Pakistan 2005, and the Sichuan 2008 earthquakes highlighted the need to protect school children.

KEYWORDS: Multihazard approach, hazard map, urban planning, sustainable cities, school buildings.

1. INTRODUCTION AND BACKGROUND

To reduce the risk of disaster, most of the solutions go through building engineering practice, reducing the vulnerability of constructions by increasing their strength. However the results are not always safe. For example during the Michoacan, Mexico, 1985 earthquake - in the Lake Zone of Mexico City located over 300 km. from the seismic source - some 3000 reinforced concrete and steel buildings collapsed or suffered severe damage beyond the possibility of retrofitting. The Mexico City Lake Zone consists of soft water-saturated soil, dozens of meters deep, where the seismic waves suffer a great amplification.

At the Marina district in the northern tip of San Francisco peninsula, during the 1989 Loma Prieta, CA, earthquake, a number of four-story high wooden apartment buildings suffered severe damage. The domestic water supply system and its first redundant water system to be used only for fire fighting, consisted of large cisterns sited on the nearby hills, to ensure water pressure, and a network of independent pipes. The main pipes of both water systems failed, either because of multiple breaks in the pipes or failure in the pipe joints. The sectors where the damage was most severe consisted of land filled from 1906 to 1917, using the rubble from the buildings that collapsed or were severely damaged in the earthquake and fire of San Francisco, 1906. Marina was also developed on beach sand and beach–dunes. During the 1989 Loma Prieta, CA, earthquake the soil acceleration was high and the soil deformation was large. These facts may explain the cause of those failures that occurred in Marina, 100 km. away form the epicenter

On the other hand, during large magnitude earthquakes that affected Lima, the capital city of Peru, during the 20th century: 1908, 1940, 1966 and 1974, ten of thousands of 100-year-old adobe constructions suffered only light damage. The reason: in Lima's historical center where adobe housing is concentrated, the soil is very compact and dry, with coarse sand matrix containing rounded stones one inch to ten inches or more in diameter, and the terrain is flat, with slight east-to-west inclination. The maximum intensity during all those earthquakes is estimated at VI to VII MMI in downtown Lima; while in La Molina, a small valley- located near the places where adobe constructions are located- surrounded by hills, where in general uncompacted residual fine grain soil predominates, the seismic intensity during all the events was IX MMI. Brick masonry and reinforced concrete buildings of the National Agrarian University La Molina (UNALM) collapsed or suffered severe damage.

These three examples illustrate the microzonation effects i.e. up to three to four degrees of difference in the seismic intensity between close locations, which also means a large difference in the damage degree sustained by the buildings. The cause of that difference is the local physical characteristics, which it is possible to investigate before an earthquake strikes, and it provides the clue to develop and apply the new approach, which consists in focusing the constructions' safety on the site's natural conditions, without disregarding the good quality of the construction itself; i.e. developing for urban purposes sectors with low or medium natural hazards and applying seismic-resistant construction technology of the 21st century.

Using this conceptual approach, in November 1998 the Sustainable Cities Programme First Stage (SCP – IS) was started in Peru, focusing on the sustainable city's first attribute: its physical safety (Kuroiwa, 2000) (Kuroiwa, 2004). The Programme is being conducted by Peru's Civil Defence (INDECI) and UNDP. It started when there was the need to reconstruct the cities and towns affected by El Niño 1997 – 98. The best argument to convince the then Prime Minister of Peru, and at the same time Chairman of El Niño Reconstruction Committee (CEREN), local authorities, and the affected communities, was the fact that the inundation maps of the main cities affected by El Niño 1997–98 were practically carbon copies of those inundation maps generated by El Niño 1982–83. The SCP-IS was expanded countrywide when the degree of damage of the Arequipa 2001 earthquake and its geographic distribution had good agreement with the Regional Seismic Scenario (RSS) developed in 1992 – 95. (Kuroiwa, 2002).

By consensus, urban plans for the capital cities of the provinces most affected by the August 15, 2007, Peru earthquake - Ica, Pisco, Chincha and Cañete - are being made for reducing the risk of disaster, based on their validated hazard maps made from September 2007 to May 2008 (Kuroiwa, 2008). Originally those hazard maps were developed under the frame of the National SCP-IS in 2001-2002.

At the time that the Ica region or Pisco, Peru, August 15, 2007 earthquake occurred, there were available the hazard maps, land use plan, and project profiles for disaster mitigation (8-10 per city) for 130 cities and towns, with 6, 4 million in habitants distributed all over the country (Kuroiwa 2007). In the macroseismic area of the Peru, August 2007 earthquake, 16 cities and towns had the set of documents as indicated. In September 2007 when it was found that the 2001-2002 hazard maps had good correlation with the real effects of the earthquake, a decision was taken to review and update those investigations, adding the towns severely damaged by the earthquake not studied previously: six in the Ica province, and four in Chincha. So there are now 26 cities and towns with the set of documents updated and being applied in their urban plan to reduce the risk of disaster.

2. THE ICA REGION OR PISCO, PERU, EARTHQUAKE AND ITS MICROZONATION EFFECTS.

On August 15, 2007, at 23:40:58 UTC, 18:40:58 local time an earthquake of Mw 8,0 (USGS) struck the south central coast of Peru. The epicenter was 13.32º S and 76.51º W, its focal depth, 39 km. (24.2 mi), and lasted more than three minutes, an unusually long duration for an earthquake of that magnitude. The event was a thrust faulting earthquake, with the Nazca or ocean plate subducting under the South American or continental plate, which are approaching each other at the rate of 77 mm per year. The earthquake generated a tsunami with a run up as high as 8 m.

The macroseismic area included three provinces of the Ica region: Ica, Pisco and Chincha, with Pisco, the capital city of the province of the same name, being the most affected. It also included the provinces of Cañete and Yauyos in the Lima region; and the provinces of Castrovirreyna and Huaytara in Huancavelica (in bold letters in Fig. 1). The death toll was close to 600 people, and approximately 1500 were injured. Some 40.000 houses collapsed, most of them of adobe, and nearly 42,000 dwellings were damaged in different degrees, that need to be retrofitted.

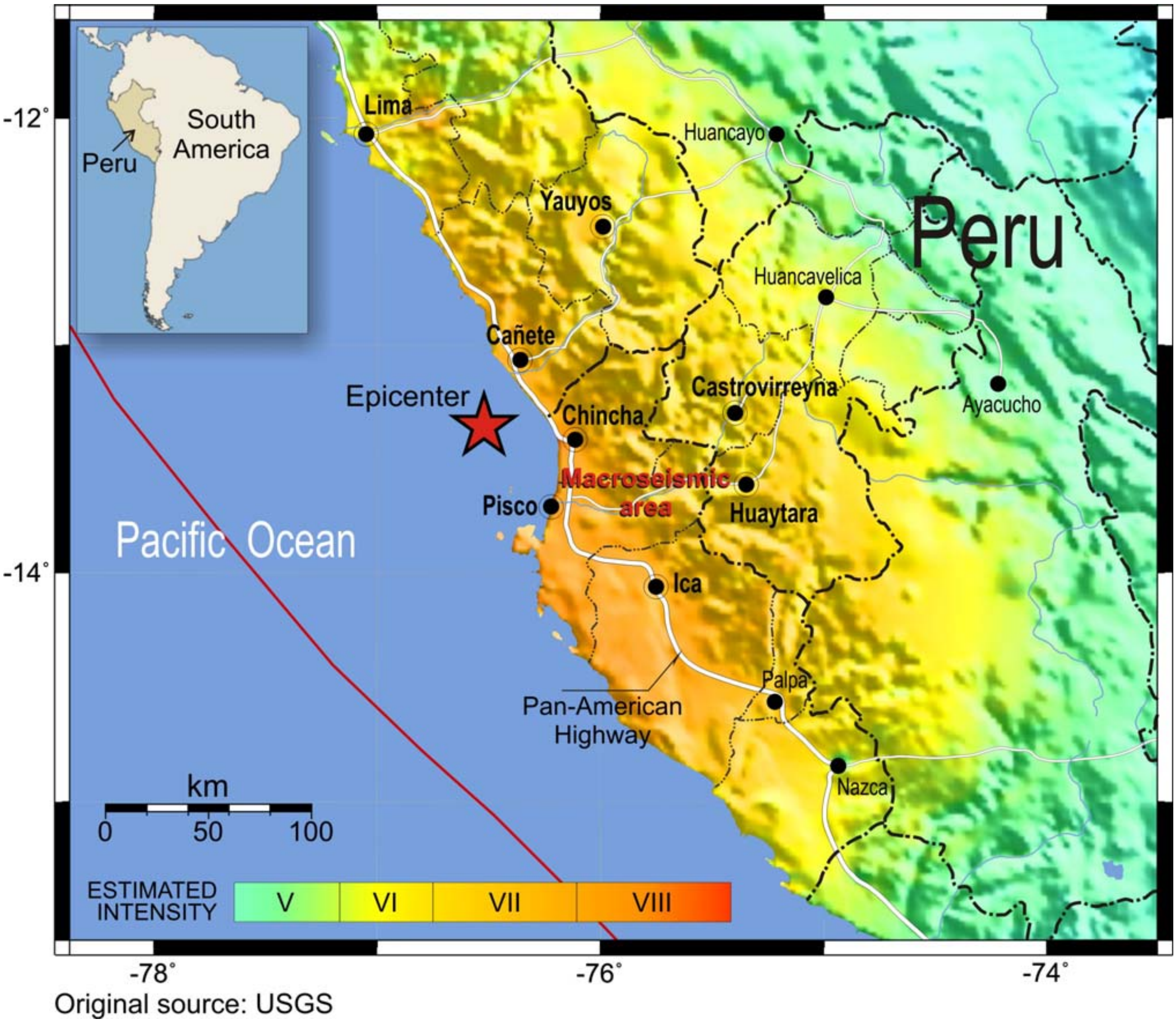

Fig. 1- Macroseismic area of the Ica region or Pisco earthquake, Peru, of August 15, 2007

From August 17, 2007, for about nine months, the author continued his systematic field damage survey focusing on its microzonation effects, advised the validation of existing maps, as well as the microzonation studies with a multihazard approach of new localities severely struck by the earthquake, not included in the 2001-2002 investigations.

Brief technical meetings were carried out with a dozen damage survey missions from the USA, Japan and other countries and their reports, kindly handed to the author, were reviewed. A summary of the results of these activities, relevant to the aim of this paper, follows.

On August 17, 2007, the rural area, west of Chincha Alta, was surveyed along the way to Tambo de Mora. In Sunampe, entire blocks of adobe houses collapsed due to their close location to the earthquake source, and the soil humidity as this rural area is irrigated by inundation. Electric transformer posts, and electrical illumination posts, which are standard in shape and size in the macroseismic area, were also taken as a reference to deduce the seismic effects on the sites. For example in Sunampe, the pole of an electric transformer remained vertical, but the oil container, located some 4 m. high, fell and was found 1 – 2 m from the pole, indicating the violence of the vibration. In Tambo de Mora, Pisco and near the Huamani Bridge close to the Pisco River, where soil liquefaction occurred, some poles collapsed and others were inclined at different angles.

Arriving from Sunampe to Tambo de Mora, large and numerous cracks were observed at the east side of Tambo de Mora, at the foot of the terrace -where Chincha Alta and Sunampe are located – indicating that extensive soil liquefaction had occurred there, as expected from the 2001-2002 investigations. At the Calle Nueva street, very close to Tambo de Mora's main square, at both sides of the street along some 300 m., brick masonry one-story dwellings had settled 0.50 to 0.90 m. (Fig. 2). The walls sunk as they transmitted their own weight and that of the reinforced concrete roof to the soil, while the houses' floors remained almost at their original level, but were severely cracked (Fig. 3). About 250 m east of the main square, an adobe evangelical church (Fig. 4) and an adobe fence (Fig. 5), did not suffer any damage, in spite of their obvious vulnerability. They are built on a cut of a small hill, on a dry, firm soil. It is also a case of clear microzonation effect. At the Provincial Jail of Chincha, located in Tambo de Mora, extensive soil liquefaction occurred and most of the buildings settled from 0.30 to 0.90 m. Lateral spread occurred there. It was clearly observed as walls moved laterally. For example, in a continuous wall, initially separated only by 2 cm -a construction joint- "a door was opened", as a portion of the wall moved laterally and then forward. (Fig. 6).

The next surveyed places were Pisco, San Andres and the beaches south of those localities. The 2001–2002 hazard map (Fig. 1, in Kuroiwa, 2008) indicated three sectors with different hazard degrees: very high, a strip parallel to the coastal line, threatened by soil liquefaction and tsunami – as in fact occurred. High, most of Pisco's central built-up area (Fig. 7). There, fine sand predominated, with the water table near the ground surface. From Pisco to the south-east side, there is an extensive area with medium hazard. The survey indicated that in general there was a good correlation between the 2001-2002 Pisco hazard maps and the real damage caused by the August 15, 2007 earthquake.

In Ica the most critical threat is flooding, as it was severely inundated during El Niño 1997–98. But in August 2007 only an earthquake occurred, so it was not possible to compare the event's effects with the envelope of the geologic-climatic hazard map. However the area worst affected by the earthquake was the part indicated by the seismic microzonation studies, as on a stepped hill covered by aeolian sand. In San Jose de los Molinos, located north of the city of Ica, a school was surveyed (Fig. 8). The different seismic behavior of those two buildings was noted. The first, designed with the 1977 Seismic Code, suffered severe damage, while the other building designed with the new 1997 Seismic Code, did not suffer any damage; this is true of all the school facilities designed with that code during the 2001 Arequipa and the Ica 2007 earthquakes. Only two small changes were introduced to Peru's 1977 Seismic Code. The permitted lateral drift was reduced by approximately 30%, and the use coefficient was increased from 1.3 for important buildings, to 1.5 for essential facilities. These two changes were crucial to eliminate the short column defect from Peruvian school buildings. But this was not only a problem found in Peru. During the Philippines 1990 and the Chi-Chi Taiwan, 1999 earthquakes, about half of the buildings that collapsed or were severely damaged were school buildings due to the short column structural defect.

The 2001-2002 hazard maps of Chincha Alta and Cañete, very accurately reflected the degree and the geographic distribution of the damage caused by the August 2007 Peru earthquake.

As of July 2008, there are validated maps, and the results of the studies of new towns investigated from September 2007 to May 2008, of 26 cities and towns which are being applied in the urban development plan of the four most important cities located in the macroseismic area, and land-use plans for the other localities.

The microzonation effects on the highways system in the macroseismic area of the 2007 Peru earthquake were reported by O`Connor, J. et al. (2007)

3. LESSONS LEARNT FROM THE FAILURE OF ESSENTIAL FACILITES DURING CATASTROPHIC EVENTS

Facilities such as hospitals, fire stations, police stations, and schools play a crucial role during disasters: attending the injured, rescuing trapped people, maintaining public order, and serving as a place of refuge for the victims. Since classes are usually suspended during the critical period immediately after the event, schools

Fig. 2- One-story brick masonry house settled some 0.70 m

Fig. 3- Notice that the walls have sunk some 0.40 m, and the floor 0.20 m

Fig. 4- Adobe walled church, on firm soil, with no damage.

Fig. 5- An adobe fence, 15 m south of the church and 200 m east from the Tambo de Mora main square, undamaged.

Fig. 6- These two portions of wall were aligned, separated by only 2 cm. An employee of the town hall is seen through "the door opened" by lateral spread.

Fig. 7- Collapse of a reinforced concrete building in downtown Pisco.

Fig. 8- The school building on the left, designed with the 1977 Seismic Code suffered short-column failure. The one on the right, designed with the 1997 SC was undamaged.

Fig. 9- Over 40,000 adobe houses collapsed mostly in rural areas irrigated by inundation. Entire blocks of houses collapsed in Sunampe, Chincha and in Hualcara, Cañete.

become available to shelter the victims. These facilities have been named as essential in the event of disaster. These indispensable buildings must therefore be very carefully planned and executed, in terms of location, design, construction, supervision and maintenance. The objective must be that they will remain operative even after very intense events. It is not enough for the structure to resist without major failures, but, as in the case of hospitals, the non-structural elements must also remain undamaged to ensure that the vital services continue uninterrupted and to prevent the loss of functionality (Kuroiwa, p.89, 2004).

When entire towns are covered by avalanches or lahars, everything is lost, including hospitals, schools, police and fire stations. For example: Yungay and Ranrahirca disappeared under 60 million m3 of rocks, ice and mud, originated in the north peak of Mt. Huascarán induced by vibrations of the Peru May 31, 1970 earthquake. Both localities were located in the drainage gully of Mt. Huascarán. In Yungay some 13,000 persons lost their lives. Ranrahirca had lost one third of its population in a 1962 avalanche. In 1970 the remaining two thirds of the town with some 3,000 people, disappeared forever.

In October 1985, during the eruption of Monte del Ruiz volcano, a tropical glazier of 5240 m., a violent eruption, but of moderate volume, melted the ice cap. The mudflow or lahar as it is named in Indonesia, with hot pyroclastic flows in some parts, and frozen water in others, rushed down the steep sides of the volcano, channeled in the bed of a narrow canyon, bringing with it the loose debris encountered on the way. Armero was located just at the exit of the canyon, in the deposition fan of Lagunillas river: roaring, violent, successive waves of volcanic mud swept the city away, uprooting buildings from below their foundations in the high-lying sector, near the outlet of Lagunillas river, and it buried them with mud flows deposited in the low-lying part, engulfing the remains of the 23000 victims, of a total population of 30000, their houses, furniture, trees, lamp posts and vehicles.

It is worth recalling the 1999 Venezuela Debris Flow and Flash Flood Disaster. The Caribbean coast of the Venezuelan state of Vargas was affected by a major storm that deposited 911 mm (36 inches) of rain from December 14 to 16, 1999. A highly developed urban conglomerate was built along Venezuela's Caribbean coast on the many alluvial fans, the only places where slopes are not too steep to build, as most of the coastal zone consists of steep mountain fronts that rise abruptly from the Caribbean Sea. The constructions included dozens of reinforced concrete multistory apartment buildings, but most of the residences were one- and two-story masonry dwellings. This highly vulnerable built-up area was a scenario poised for disaster. Late in the night of December 15 and early in the morning of December 16 multiple debris flows and flash floods covered the alluvial fans east of Maiquetia, the Caracas International Airport, along Venezuela's Caribbean coast, causing some 15000 victims and nearly ten billion US Dollars in material losses.

4. PROTECTING SCHOOL CHILDEN FROM THE RISK OF DISASTERS

The North Pakistan or Kashmir 2005, and the East Sichuan, China, 2008, earthquakes have highlighted the need to protect young students from losing their lives under the ruins of their own school buildings. As students spend many hours in their educational facilities, the probability that the event might catch them there is relatively high, as happened in those two earthquakes.

During the Pakistan 2005 earthquake, of the total death toll of 93,500, nearly 18,000 were students and teachers. In the Sichuan, China, 2008 earthquake, according to news published in the New York Times on May 13, 2008, in Juyuan a middle school collapsed, trapping under the building's ruins 900 students and teachers, and at a school in Dujiangyan, a similar disaster occurred: the state–run Xinhua News Agency reported that 1000 students and teacher were dead or missing.

The earthquake magnitude was Mw 8.3 according to CEA (Chinese Earthquake Administration), and Mw 7.9 reported by the USGS (United States Geological Survey). It occurred at 14:21:01 local time, when schools were full of students. The focal depth was shallow, 19 km (12 mi), and this fact, added to the local site characteristics, such as mountainous topography, resulted in a high intensity X MMI causing numerous landslides. The epicenter was located 80 km. (50 mi) W-NW of Chengdu, Capital city of Sichuan province. In the Sichuan province, rural area schools were very vulnerable constructions with no seismic design. These facts may explain why in certain areas, entire neighborhoods were razed. As of July 2008 the official death toll was reported to be 69,179; with 18,340 missing, and 374,176 injured.

Officially it was estimated that more than 7,000 schoolrooms had collapsed, killing thousands of students. Because of the country's one-child policy, many families lost the only child they had. In reaction to this disaster, safety checks are to be carried out at schools across the country. Also, an amendment has been drafted, to improve construction standards for primary and middle schools in rural areas.

Lessons left by the Aberfan School Disaster should be remembered, especially in mountainous mining areas, such as those in the Peruvian and Chilean Andes. On a foggy morning, at 9:15 a.m. on October 21, 1966, a tremendous sound was heard from the Merthyr Mountain at Aberfan, a mining village located in South Wales, UK. A tip of coal waste slipped onto Aberfan very quickly, because of a week of heavy rainfall. It first destroyed a farm cottage in its path, killing all the occupants, then engulfed the Pantglas Junior High School located just below, and some 20 houses before coming to rest. In all, 144 people died in the Aberfan disaster and 116 of them were young school children.

5. CONCLUDING REMARKS

If catastrophic disasters are to be avoided, such as those that occurred in Yungay and Ranrahirca, Peru, during the 1970 earthquake, and that of Armero, Colombia, during the eruption of Monte de Ruiz Volcano in 1985, and in the state of Vargas, during the Venezuela Debris Flow and Flash Flood Disaster, sectors with very high natural hazards like these need to be prohibited for urban uses, as stated in the SCP-1S methodology. High-hazard sectors have some restrictions for urban use. For example, adobe housing is not permitted where high seismic acceleration is expected – most commonly on soft water-saturated fine soil, as reported by Idriss, I.M. (1991) and Seed, R.B. et al (2001), and observed by the author at many locations in the Americas, and where the site remains under water for several days. If population densification and city expansion takes place on sectors with low or medium natural hazards and applying the seismic-resistant construction technology of the 21st century, the loss of lives and properties is drastically reduced. The Peruvian Seismic Code of 1997 and the new one of 2003, permit hospitals and school buildings to be located only in low- or medium-hazard sectors.

The SCP-1S started in 1998, when there was a need to reconstruct the cities affected by El Niño 1997-1998, and it was expanded countrywide after the Arequipa 2001 earthquake. By consensus it was decided to develop the urban plans of the important affected cities based on their validated hazard maps. However there is still much to be done, especially to upgrade the capacity of the local governments, and the ten years of continuous development of the SCP-1S, 1998-2008, must go on during the years to come in order to be sustainable. On June 28, 2008 it was proposed to 300 mayors from all over the country, during the Annual 2008 General Assembly of the Peruvian Association of Municipalities (AMPE) that the SCP-1S be used as a route map by the 1832 Peruvian municipalities for the period 2008 to 2021, Bicentennial of Peru's Independence.

ACKNOWLEDGMENTS

To the Department for International Development of the United Kingdom (DFID, UK), that funded most of the technical/scientific investigations made on the effect of the Ica region, Peru, 2007 earthquake, which were carried out by the UNDP/Peru. The author is indebted to these two institutions. To the authorities of Peru's Civil Defense (INDECI) and the Ministry of Housing, Construction and Sanitation (MVCS). The author thanks the foreign damage survey missions that visited Peru, and handed him their reports on the Peru 2007 earthquake.

RERERENCES

Idriss, I.M. (1991). Earthquake Ground Motions at Soft Soil Sites. Proc. 2nd. Intern. Conf . on Recent Advances in Geotech. Earthq. Engg. and Soil Mechanics, pp 2265-2273. St. Louis. MO. USA.

Kuroiwa, Julio (2000) Development of Sustainable Cities 1st. Stage. Proc.6th ICZ. Organized by EERI. Palm Springs. CA USA. On CD-Rom.

- (2002) Sustainable Cities, a Regional Seismic Scenario and the 6-23-2001 Arequipa Peru Earthquake. In Natural Hazard Review an ASCE publication. Vol. 3, Number 4, pp. 158-162.

- (2004) Disaster Reduction - Living in Harmony with Nature, book in English, 512 pages, presented during UN World Conference on Disaster Reduction. Kobe, Japan. January 2005. Information in the USA: International Code Council (ICC) Phone: 1-888-ICC-SAFE (422-7233). Int´l calls 01-708-799-2300.

- (2007). Integrated Natural Risk Reduction through a Sustainable Cities Programme Proc. of the Reduction Hyperbase (DRH) Contents Meeting. Kobe, Japan, 12-13 March 2007, NIED & Edm Editorial Team, November 2007, 366 p, pp 61-67

- (2008). Reconstruction of Ica, Pisco, Chincha and Cañete, Peru, Based on updated Hazards Maps. Proc. Sixth National Seismic Conference on Bridge & Highways, Charleston, SC, USA, July 27.30, 2008.

O'Connor J., Mesa and M. Nykamp (2007), Damage to the Highway System from the Pisco, Peru Earthquake of August 15, 2007. Technical Report MCEER-07-0021, 92 p., U.S. Department of Transportation Federal Highway Administration. New York State University at Buffalo, N.Y. USA.

Seed, R. B. et al. (2001). Recent advances in soil liquefaction engineering and seismic site response evaluation. Proc. 4th Intern. Conf. on Recent Advances in Geotech. Earthq. Engg. and Soil Mechanics. Paper No. SPL-2, 45 p. San Diego, CA. USA.