Available online at www.sciencedirect.com

ScienceDirect

Procedia Economics and Finance 18 (2014) 408 – 415

Procedia Economics and Finance

www.elsevier.com/locate/procedia

4th International Conference on Building Resilience, 8-11 September 2014, Salford Quays, United Kingdom

Peru sustainable (resilient) cities programme 1998-2012. Its application 2014 - 2021

Julio Kuroiwa *

Professor Emeritus. National University of Engineering, Lima, Peru. Member of the Advisory Panel 2010-2015 Making Cities Resilient. My City is Getting Ready. UNISDR. Av. Del Parque 442. Lima 27- PERU.

Abstract

The Maule 2010, Chile, and the Tohoku-Oki 2011, Japan, earthquakes have reconfirmed that superficial geology is critical in the seismic intensity, and for predicting the occurrence of soil liquefaction, one of the most damaging seismic effects.

From 1998 to 2012 multihazard maps, land-use plans for reducing risk, and disaster mitigation project profiles were developed for 175 Peruvian cities by Peru's Civil Defense (INDECI) and UNDP. During the Ica, Peru, 2007, earthquake, the actual damage distribution in Pisco, Tambo de Mora and other cities, agreed very well with the multihazard map developed six years before, showing how useful those maps are. Kuroiwa and Delgado (2012). In 2013 the author proposal to Peruvian Engineers Association (CIP) and INDECI to complete the SCP, so that in 2021, the year of Peru's Bicentennial of its Independence, most of the 175 cities may have their SCP implemented.

Selection and/or peer-reviewed under responsibility of the Centre for Disaster Resilience, School of the Built Environment, University of Salford.

Keywords: Sustainable cities, resilient buildings; multihazard map; land-use plan; disaster reduction.

* Corresponding author. Tel.: (511) 719-3556; Telefax: (511) 719-355.
E-mail address: jkuroiwa@drperu-international.com

Selection and/or peer-reviewed under responsibility of the Centre for Disaster Resilience, School of the Built Environment, University of Salford.
doi:10.1016/S2212-5671(14)00957-5

1. Introduction

One of the most effective ways to protect cities from intense natural phenomena in built-up environments or for planning new cities or large industrial complexes in disaster-prone countries is by applying multihazard maps in their development.

To formulate a multihazard map, it is necessary to consider all natural and man-made activities that threaten the area of interest, such as seismic effects, flooding caused by intense rains or tsunamis, and soil failure, such as landslides and soil liquefaction. Then the cities and the foreseen expansion areas are divided into sectors with different degrees of hazard: low, medium, high and very high. The same procedures are applied for new cities and for the location of large industrial facilities. For existing cities, population densification and urban expansion take place in sectors with low or medium hazards. Sectors with high hazard are used for urban purposes after a detailed site investigation is made, and sectors with very high hazard are not permitted to be used for urban occupation.

The Maule, Chile, Mw 8.8, of February 27, 2010, University of Chile. (2010), EERI. Special Earthquake Report. (2010); and the Tohoku-Oki, Japan, Mw 9.0, March 11, 2011, The Government of Japan, GFDRR and the World Bank (2011) have reconfirmed that local soil characteristics, geology and topography are critical in the seismic and tsunami intensities, and also in the geographic distribution of damage and material losses. Both events have shown that soil liquefaction, which occurred extensively in Chile and Japan in 2010 and 2011 respectively, is one of the most damaging secondary effects of large magnitude earthquakes.

In Chile, infrastructures such as roads and bridges suffered severe damage and mining tailings located a few hundred km from the epicenter collapsed or suffered severe damage. In Japan, at the borders of Tokyo Bay and rivers that flow into that bay or to the Pacific Ocean, north of Tokyo and some 300 km south from the epicenter– soil liquefaction caused severe damage to buildings that settled or tilted. Infrastructure such as water distribution systems suffered large soil deformation which caused the breakage of pipes and their connections. Extensive liquefaction that occurred both in Chile and in Japan may be explained by the fact of the occurrence of very large magnitude earthquakes, and consequently with long duration –three or more minutes– that caused the gradual increase of the water pore pressure and finally extensive soil liquefaction.

Implementing a resilient city is complex and involves many aspects. Some of the most important lessons learnt from past disasters and the latest advancement of science and technology are included in order to protect the life of citizens and reduce damage to buildings, especially essential facilities such as hospitals and infrastructure focused on lifeline services: water, energy, and transportation.

2. Development of Multihazard Map in Peru

2.1 Microzonation effects in Metropolitan Lima

During destructive earthquakes that struck Lima, the capital city of Peru, in 1908, 1940, 1966 and 1974, seismic microzonation effects were very clear i.e. sectors few km apart, had 3 to 4 degrees of difference in the Mercalli Modified (MMI) seismic intensity scale. In La Molina, a relatively narrow valley east of Lima surrounded by hills, with soil consisting mainly of uncompacted fine sand generated nearby by rock decomposition, the intensity was IX MMI during those four events, causing the collapse of, or severe damage to, masonry buildings in 1908, and destruction of reinforced concrete buildings, most of them at the campus of the National Agrarian La Molina (UNALM) in 1940, 1966 and 1974, including retrofitted buildings after the 1966 earthquake, which were then damaged again during the 1974 event, even though they had been designed and constructed using reinforced concrete and seismic technologies of those years and had been supervised by a multilateral loan organization.

Meanwhile in the center of the Rimac Valley, there is 100-year old adobe housing that practically did not suffer any damage. There the soil consists of conglomerate carried by the torrential Rimac River, so, rounded stones 2” to

10” predominate with soil matrix of compact coarse sand, and with a small percentage of fine soil; the area is flat and the ground water level is a dozen meters below the soil surface. During the four destructive earthquakes that affected Lima in the 20th century, consistently in La Molina the seismic intensity was IX MMI, while in the center of the Rimac Valley where most of the city is located, the seismic intensity was V-VI MMI.

Inspired by what happened in Lima, since the early stage of the author’s research development, it was clear that the site microzonation effects were very important to investigate. So during the damage inspection of 23 of the most destructive disasters that occurred in the Americas and a few in Japan and China in the last four decades, the field investigation was focused on the microzonation effect. Most of them were earthquakes, but also: vulcanism, Armero, Colombia, 1985; hurricanes, Andrew, 1992, FL, Katrina, LA, 2005; the 1999 Venezuela debris flow and flash flood disaster; and practically all climatic disasters occurring in Peru; and the tsunamis of 2001 and 2007.

The field surveys were made focusing on the microzonation effects and their relation with damage to buildings and infrastructure. One of the surveyed earthquakes was the Michoacán, Mexico, 1985 earthquake. As in the case of La Molina, Lima, Peru, in Mexico City the microzonation effects were very clear, repeatedly. Located some 300 km from the Pacific coast subduction zone, during the 1957, 1979 and 1985 Mexico earthquakes at the Lake zone of Mexico City, consisting of fine water saturated soil, the damage was severe. In 1957, 95.4% of the damage was in the Lake zone, 4% in the transition area, and only 0.4% in the extended stiff soil. In 1985 in the Lake zone some 3,000 reinforced concrete and steel buildings collapsed or were damaged beyond the possibility of recovery. The most important hospitals in Mexico City, all located in the Lake zone, collapsed or were severely damaged. Almost 6,000 hospital beds were lost. Since then the Pan American Health Organization – PAHO has been promoting the Programme ‘Safe Hospitals in Latin America and the Caribbean’, with uneven results. The main conclusions of the survey of the 1985 Michoacán earthquake in the Pacific Ocean macroseismic area near the seismic epicenter, was that most of the structural damage to buildings was due to the lack of adequate design to resist earthquakes, which caused stress concentration in elements that were severely damaged, such as short columns, soft story and sudden reduction in plan, eccentricity and torsion, and failure from insufficient stirrups or anchorage of steel bars in reinforced concrete buildings. The second conclusion was the strong influence of the natural site conditions on the seismic intensity and the geographic damage distribution. These lessons may be useful to decide what to do with millions of old vulnerable buildings existing in the world’s seismic regions.

Conclusions for other earthquakes in Peru, and other Latin American countries, and in California: San Fernando 1971, Loma Prieta 1985 and Northridge 1994, were the same as in the coastal region of Mexico in 1985. In the case of the Northridge earthquake, the damage to the water distribution system had a clear correlation with the soil characteristics i.e. the damage to water pipes occurred where the soil deformation was very large due to soil liquefaction or there had been high seismic intensity.

In the cases of the volcanic disaster of Armero, Colombia, 1985; the flooding of 80% of the city of New Orleans, Louisiana, caused by the hurricane Katrina in 2005, and the Venezuela 1999 debris flow disaster, the topography of the area played a key role in the cause of the disasters, the intensity of the flows and the geographic distribution of damage and material losses.

During the Kobe, Japan, 1995, earthquake, those buildings designed with seismic codes developed after the 1980s suffered minor structural damage; however, a new problem arose: non-structural elements and building contents were a large percentage of the total losses. Due to damage during the Northridge CA 1994 earthquake, the new highly seismic-resistant new Oliview Hospital was put out of service. The breakage of water pipes inundated areas, making it impossible for the hospital to be operative. The Tohoku-Oki, 2011 earthquake clearly shows the advancement of Japan’s Earthquake Engineering: outside the tsunami inundation zones, steel and reinforced concrete buildings responded adequately to very strong earthquake shaking. Seismic isolators and seismic dampers demonstrated how useful they are to reduce the seismic input on constructions. For example, in Sendai city a tall multistory building was undamaged with intensity X MMI.

(a)

(b)

Fig.1 (a). Non-structural damage at the Customs Office a three-story R.C. building in Pisco city, Peru. Intensity VIII MMI. 1(b). Damage to contents in SUNAT, 14-story RC building in Lima, Peru. Both damaged by the Ica Region earthquake Mw 8.0 (USGS) of August 15, 2007.

In Chile, with modern Earthquake Engineering technology, there occurred the collapse of new buildings or severe damage to infrastructure in sites with high seismic intensity or where soil liquefaction occurred. Of the total losses of over US$ 30 billion reported by the Chilean Government to the UNDP/Chile, about 70% corresponded to non-structural and building content damage. The Santiago de Chile International Airport was inoperative for about three weeks for the same reason; there was also non-structural damage to some Chilean hospitals and the disarray of medical records that needed to be reorganized, EERI. Special Earthquake Report. June (2010). The Ica Peru 2007 earthquake caused non-structural damage and building content losses. Fig.1 (a) and (b).

2.2 Instrumental records confirm the influence of natural site characteristics on seismic intensity in Mexico City and La Molina, Lima, Peru

At the Lake zone in Mexico City and in La Molina, Lima, Peru, microzonation effects occurred many times during the 20th century. Researchers from the National Autonomous University of Mexico (UNAM) recorded the acceleration of the 1985 Michoacán earthquake, at different distances from the epicenter: At the port of Lazaro Cardenas near the seismic source, on stiff soil, the recorded peak acceleration was 12 cm/s^2. In Mexico City, 300 km from the epicenter, the earthquake was recorded with nine instruments, five in the extensive stiff soil, where peak acceleration was 50 cm/s^2. At the Lake zone four accelerograms were recorded, and the peak acceleration was 150 cm/s^2 with several sinusoidal waves of about 2.0 seconds and severe damage was caused to buildings by soil-building resonance. Those accelerograms clearly show large seismic amplification of seismic waves at the Lake zone with soft water-saturated soil over ten times (150/12) more than the stiff soil near the seismic epicenter and in Mexico City three times more (150/50).

During a La Molina seismic experiment, in February and March 1984, 15 earthquakes of magnitude around 4,0 Richter were recorded in seven seismometers deployed in La Molina, one on rock outcrop designed as the “master station” and six on the filled soil in two alignments along the length and width of the valley. The other two were installed on the hill separating La Molina from the Rimac Valley and the last one in Surquillo almost at the center of the Rimac Valley which is flat and has dry, stiff soil. The spectral ratio and frequencies between La Molina/Rock and Lima/Rock for the frequencies of interest for engineering 1 to 10 CPS or T = 0.1 to 1.0 s, varied from 3 to nearly 10, indicating large amplification of the seismic waves in La Molina, for small magnitude earthquakes.

2.3 State-of-the-Art in the Development of Multihazard Maps in Peru

After the occurrence of the Ancash, Peru, earthquake of 1970 with a death toll of 67,000 victims, which was the most deadly disaster in the Americas during the 20th century, the Japanese Scientific Mission (JSM) from the University of Tokyo spent four months developing the multihazard map of Chimbote city, including seismic effects and flooding, using the latest technology and equipment. Former Peruvian students in Japan, including the author, assisted the JSM in the field investigations and data processing.

In the 1980s when it was necessary to investigate the site characteristics of the location of an experimental nuclear reactor, the requirements of the International Agency of Atomic Energy of the UN sited in Vienna, Austria were applied by the author and his team. This was requested and supervised by two important British corporations in the field of the construction industry and energy generation.

The methods developed in Peru were relatively costly and sophisticated for a developing country like Peru. Based on those two experiences, damage survey of natural disasters in the Americas and Asia, and updating the international theoretical and experimental advancements, a simplified low-cost method was developed in Peru for wide application. It was used from 1998 to 2012 to develop the multihazard maps of 170 Peruvian cities, including land-use plans for disaster reduction and project profiles for disaster mitigation, as shown in Table 1. For more than a decade, with no interruption, Peru's Prime Minister's Office provided the necessary funds; INDECI conducted the SCP, and the UNDP-Peru provided advice and some additional funds. The author was the chief technical adviser to the SCP.

However, the local governments responsible for implementing the Sustainable Cities Programme (SCP) in Peru had neither the technical capacity nor the economic possibilities. But with the continued improvement of the country's economy during the last decade, local governments now have funds to implement the SCP. Under the framework of an agreement signed in 2014 between Peru's Civil Defence (INDECI) and the Peruvian Association of Engineers (Colegio de Ingenieros del Perú, CIP) with over 150,000 members, these institutions are using their regional branches to attempt to implement the SCP so that by 2021, the year of the Bicentenary of Peru's independence, most of the 170 provincial and district capitals may have implemented their SCP. The working plan is being focused on upgrading the capacity of local authorities, engineers, architects and the students of those specialties, with effective participation of the concerned communities. Some encouraging results can be reported. Three new cities of large international mining corporations have successfully developed their resilient cities:

- El Pinar in Ancash by the Antamina Mining Co, with Canadian and Japanese investments.
- Nueva Fuerabamba in Apurimac by Xstrata, a Swiss company, and
- Nueva Morococha of Chinalco from China.

The author's working group developed the multihazard maps of the two first new cities and reviewed the investigations made by a well known international consulting company of the third new city. The velocity of the S wave, Vs, were measured at different location. The cost and time have been sustainably reduced by applying the Multichannel Analyses of Surface Waves – MASW: this is an important parameter for soil classification in modern seismic codes, for example, in the International Building Code being used in the Americas.

Table 1. Sustainable cities programme in Peru 1998-2012

Region	Cities, showing population in thousands
1 TUMBES -------------	- Tumbes (88.4*), Aguas Verdes (10.3), Zarumilla (22.5), Papayal (5.0).
2 PIURA ----------------	- Talara (135.0), Sullana (180.0), Paita (57.4), Sechura (16.7), Chulucanas (55.2), Huancabamba (6.8), Ayabaca (6.0), Castilla (115.0), Catacaos (64.3), Piura (450.4), Suyo (1.5).
3 LAMBAYEQUE ----	- Chiclayo (535.4), San José (7.59), Pimentel (14.2), Santa Rosa (13.0), Monsefú (24.6), Eten (11.9), Puerto Eten (2.5), Reque (9.7), Morrope (4.7), Túcume (6.7), Lambayeque (40.9), Ferreñafe (32.3), Olmos (36.6), Picsi (4.8).
4 CAJAMARCA ------	- Cajamarca (98.2), Baños del Inca (5.35), Jaén (54.7).
5 LA LIBERTAD -----	- Trujillo, Cercado de Trujillo, Florencia de Mora, Victor Larco, El Provenir, La Esperanza, (615.0), Pacasmayo (26.1), San Pedro de Lloc (12.2), Guadalupe (20.7), Huanchaco (44.8).
6 ANCASH ------------	- Chimbote (313.2), Huarmey (17.1), Carhuaz (7.2), Recuay (3.1), Catac (2.6), Ticapampa (2.5), Huaraz (93.3), Caraz (11.3), Yungay (5.9), Ranrahirca (0.8).
7 LIMA ------------------	- San Vicente de Cañete (40.8), Cerro Azul (6.6), San Luis (11.7), Imperial (35.7), Nuevo Imperial (14.5), Lunahuaná (3.8), Quilmaná (12.5), Asia (14.1), Mala (22.8), San Antonio (3.4), Chancay (38.0) Huacho (63.2), Supe Puerto (12.4), Barranca (55.0), Paramonga (30.5), Chosica (145.5), Santa Eulalia (5.5), Ricardo Palma (3.9), Matucana (4.4), Laderas de San Juan de Lurigancho (8.0), Huaral (70.8), Huachipa (11.6).
8 ICA --------------------	- Ica (138.5), San José de los Molinos (2.9), La Tinguiña (30.1), Parcona (29.6), Subtanjalla (16.2), Guadalupe (8.3), Santiago (5.7), Los Aquijes (2.5), San Juan Bautista (0.9), Tate (2.0), Pueblo Nuevo (1.5), Palpa (8.2), Nazca (37.7), Chincha Baja, Tambo de Mora, Chincha Alta, Pueblo Nuevo, Sunampe, Grocio Prado, Alto Larán (143.8), Pisco y San Andrés (64.6).
9 AYACUCHO --------	- Ayacucho (107.4), Huanta (26.1).
10 AREQUIPA --------	- Arequipa (1,073), Cocachacra (6.6), Punta de Bombón (6.3) Dean Valdivia (4.9) Camaná (51.4), Chuquibamba (4.1), Caravelí (3.2), Aplao (3.5), Corire (2.1), Cosos (1.4), La Real (0.5), Huancarqui (1.4), Lara (2.9), Viraco (1.9), Pampacolca (2.7), Machaguay (0.6), Islay Pto Matarani (5.0) Mollendo (25.0), Huanca (1.5), Lluta (0.6), Callalli (1.8), Sibayo (0.8).
11 PASCO -------------	- Oxapampa (14.2)
12 UCAYALI ----------	- Pucallpa (272.6).
13 MOQUEGUA ------	- Omate (1.7), Puquina (1.5), Moquegua (36.0), Ilo (73.8).
14 TACNA ------------	- Locumba (1.1) Cercado, Pocollay, Gregorio Albarracín, Ciudad Nueva y Alto Alianza (242.7), Tarata (4.7), Candarave (2.3).
15 CUSCO ------------	- Cusco (256.0) Ollantaytambo (2.5), Urubamba (11.4), Calca (10.5), Pisac (2.6), Sicuani (37.1), Anta (16.3), Zurite (3.7), Lucre (3.9), Urcos (10.1), Limatambo (9.1) Taray (4.3), Santa Teresa (7.0), Machu Picchu(4.4).
16 MADRE DE DIOS	- Puerto Maldonado (35.2), Iberia (6.0), Iñapari (1.3).
17 APURIMAC -------	- Abancay (43.9).
18 SAN MARTIN -----	- Moyobamba (37.3), Tarapoto (87.9), Juanjuí (18.0), Bellavista (8.2), San Hilarión (3.0), Lamas (11.3), Nueva Cajamarca (15.8), Yuracyacu (3.8), Rioja (19.0).
19 AMAZONAS ------	- Chachapoyas (24.5).
20 JUNIN --------------	- Huancayo (323.1), San Ramón (15.4).
21 HUANUCO --------	- Huánuco (149.2), Ambo (8.0)
22 HUANCAVELICA	- Huancavelica (41.3).

Fig. 2. Peru's regions and investigated cities location map. Additionally four cities in Ecuador ★ were studied with the support of the Organization of American States. With the participation of professors and researchers of National Universities located in the regions ✚.

3. Latest Advancement in Science, Technology and Business Management to Reduce Disasters

The dramatic effects of the 2005 Indian Ocean Tsunami and Tohoku-Oki 2011 earthquake and tsunami are impulsing the international community to effectively reduce disasters, applying the latest advancement in Science and Technology, such as paleotsunami research, coseismic deformation; also business management which is permitting the development of sustainable cities holistically including building resilience, which is by far the most numerous component of any city.

Paleotsunami research explores the occurrence of ancient tsunamis going back several thousand years. Even in Japan, where there are more historical data than in the Americas, paleotsunami research has made it possible to assert that the 2011 Tohoku-Oki tsunami had a return period of 1000 years, by analyzing tsunamis deposition on a cliff at the Oya beach, Kensenunma city, Miyagui prefecture. Also that the Jogan 869 A.D. tsunami had practically the same characteristics as the 2011 Tohoku Oki 2011 tsunami in the plain where Sendai –the largest city of Tohoku region– is located. Analyzing tsunami deposited layers by Carbon 14 radioactive techniques it is possible to determine the date of occurrence of past tsunamis. For example, in January 1700 a destructive tsunami struck the coast of Sanriku, Japan, but its origin was unknown Paleotsunami research done some years ago on the northwestern coast of the USA, revealed that in 1700 $\pm$ 10 years a large earthquake originated at the Cascadia subduction zone generated a large tsunami destructive in the States of Washington, Oregon, and northern California. The results of paleotsunami investigation permit the estimation of tsunami return periods, for example every 100, 500 or 1000 years, necessary for engineering decision-making for urban development and designing buildings and infrastructure, according to their importance.

Coseismic deformation

During the generation of the Tohoku-Oki earthquake and tsunami, the earth crust underwent vertical and horizontal deformation. The measurements were made in one of the most densely instrumental regions of the world.

Coseismic vertical displacement occurred between the Japan Trench and the coastal border. Fig. 3a, 3b and 3c show the process of coseismic GPS displacements for the Tohoku-Oki main shock Mw 9.0 (yellow), and the Mw 7.9 after shock, Fig. 3a. The Fig. 3b (above) shows the observed (green) and predicted (white) deep ocean tsunami record of the Tohoku-Oki earthquake and (below) GPS vertical coseismic surface displacement (circles colored and scaled with amplitude as well as modeling predicted vertical sea-floor displacements (filled contours)). Fig. 3c, Interseismic surface deformation (blue vectors) measured by the GEONET continuous GPS network.

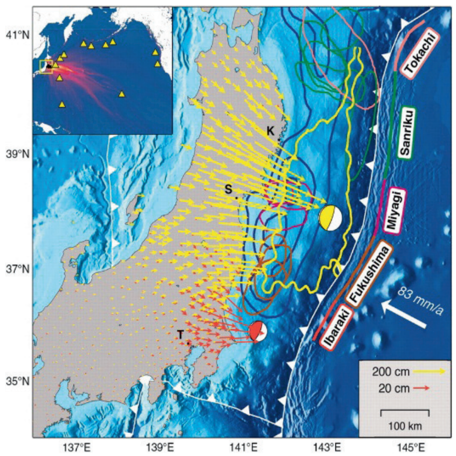

Fig.3(a). Coseismic horizontal displacement.

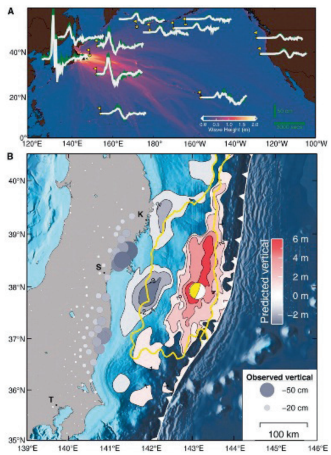

Fig.3(b). Coseismic vertical displacement.

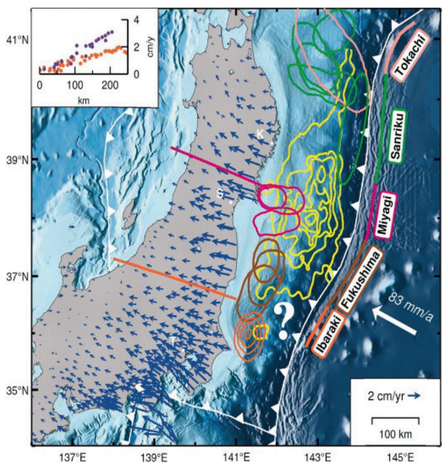

Fig.3(c). Interseismic surface deformation.

Source: Mark S. et al Science 17 June 2011.

Using the macroseismic information of the Lima-Peru 1746 earthquake and tsunami, the most destructive event in the last 500 years when Lima was destroyed and Callao razed by a 7 m tsunami wave that killed 4800 of the 5000 inhabitants of the port of Callao, researchers from the Universities of Tohoku, Japan, the University of San Marcos and National University of Engineering of Lima, Peru, together with the Peruvian Navy (see Adriano B. et al 2013), created a tsunami generating coseismic displacement model to propagate tsunami in the ocean. The tsunami waves were recorded at coast edge in three virtual mareographs, resulting in a run up of 9 m a La Punta, 10 m at the port of Callao and 22 m at the foot of the cliff of Lima bay. However, these results need to be used carefully as the batimetric data grids need more precision. The Peruvian Navy is improving the batimetry data offshore Lima and Callao.

The interruption of the production of an automobile engine key component that was being manufactured in the Tohoku region reduced the production of more than half a million cars during six months in Japan, the rest of Asia, Europe and the USA. Many small and medium industrial and retail companies at the macroseismic and tsunami inundation zones did not have business continuity planning (BCP) and many of them went bankrupt. In Peru and in other developing countries, the analyses of the life cycle of an industry do not adequately include the cost of operation and maintenance, which may be over 80% of the total project investment. The maintenance cost may need to include -- if the industrial plants are damaged -- retrofitting, replacement of equipment and business interruption, and this may be very costly. So in many developing countries, BCP and BCM (Business continuity management) need to be implemented.

Conclusion

Engineered buildings are adequately protected from intense earthquakes; however non-engineering constructions in developing countries are a high risk for their residents. In spite of the importance of multihazard maps to obtain the first attribute of a sustainable city -its physical safety- their application is limited. Nevertheless, we hope that this paper, with its holistic approach, will be useful as a guide for developing countries and will emphasize unequivocally the need for the pertinent authorities to ensure that their buildings are resilient and their cities sustainable.

Acknowledgement

To Peru's Prime Ministers in office from 1998 to 2012, to the Secretary of State of DFID U.K. in office in 2007. To UNDP, USAID and JICA for providing important support to the research reported in this paper.

References

Adriano B., Mas E., Koshimura S., Fujii Y., Yauri S., Jimenez C., and Yanagisawa H. Tsunami Inundation Mapping in Lima, for Two Tsunami Source Scenarios. Journal of disaster research. Vol. 8. N° 2 Mar. 2013.

EERI. Special Earthquake Report. June 2010 Learning from Earthquake. The Mw 8.8 Chile Earthquake of February 27.2010.

Kuroiwa J. and Delgado A. Resilient Cities - an Effective Way to Reduce Disasters Proceeding. 15th World Conference on Earthquake Engineering. 24 to 28 September 2012. Lisbon, Portugal.

Mori J. and Eisner R. Guest editors. Earthquakes Spectra. Special Issue on the 2011 Tohoku-Oki Earthquake and Tsunami. Volume 29, Number S1, 5009.

Simons M., Minson S., Sladen A., Ortega F., Jiang J., Owen S., Meng L., Ampuero J., Wei S., Chu R., Helmberger D., Kanamori H., Hetland E., Moore A., Webb F.. The 2011 Magnitude 9.0 Tohoku-Oki Earthquake: Mosaicking the Megathrust from Seconds to Centuries. Science 17 June 2011: Vol. 332 no. 6036 pp. 1421-1425.

The Government of Japan, GFDRR and the World Bank. The Great East Japan Earthquake. Learning From Megadisasters. Proceeding of the International Conference. Tokyo, Japan. October 2012. In CD-room.

University of Chile. Faculty of Physical Sciences and Mathematics. Department of Civil Engineering. Mw = 8.8 Chile Earthquake of February 27, 2010. Report of 323 p. in Spanish.