16th World Conference on Earthquake, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 4857 (Abstract ID)

Registration Code: S-W1463089696

RESILIENT CITIES AGENDA FOR THE 21st CENTURY

J. Kuroiwa[(1)], A. Delgado[(2)]

[(1)] *Professor Emeritus, National University of Engineering, Lima, Peru. UNISDR, Geneva, Making Cities Resilient: My City is Getting Ready. Member Advisory Panel 2010-2015. jkuroiwa@drperu-international.com*

[(2)] *Technical Manager, Disaster Risk Reduction Peru International SAC, Lima, Peru, adelgado@drperu-international.com*

Abstract

The Earth's global warming and its multiple negative effects is at present the main concern of mankind. After more than 40 years of fruitless negotiations, on April 22, 2016, a record 171 countries signed a historic agreement to control the emission of Green House Gases (GHGs). The global warming has the worst impact on the biosphere and on the human and asset concentration in cities. The resilient cities initiative (RCI) is ongoing worldwide, and includes a large number of important cities, such as New York, Paris, and Melbourne. But cities located in seismic regions, such as Tokyo, Los Angeles, Santiago de Chile and Lima are adequately including disasters of geological origin, such as earthquake and tsunamis, considered in the multihazard map, base for planning safe cities.

It is under this view that Peru's Sustainable City Programme 1998-2015 is presented. At the end of 1998, when it was necessary to reconstruct the northwest cities of Peru that had been severely affected by El Niño 1997-98, it was found that the inundation maps of El Niño 1997-98 were carbon copies of the El Niño 1982-83. This was the best argument to convince the then Peruvian Prime Minister and at the same time Head of the El Niño Reconstruction Committee- CEREN, as well as the local authorities of the affected cities that the reconstruction of the cities needed to be done based on multihazard maps, which include flooding by El Niño and earthquake effects.

From 1998 to 2015, the multihazard map, land-use plan to reduce disasters plus four to eight disasters mitigation profiles were produced for 175 Peruvian cities, that have received important national and international recognition. Early 2015, it was considered that it was the right time to initiate the adaptation of the Peru Sustainable City Programme to Resilient Cities Initiative (RCI). As a case study of adaptation, the city of Sullana has been selected. Lima, the capital city of Peru with 2,819 km^2, and a population of 9.45 million people, has a number of disaster reduction investigations. At the same time, to consolidate those studies, the resilient cities initiative model is being applied in the city planning of future Lima. Up to now, the Sustainable City Programme in Peru was focused on the physical safety of cities, considering disasters of geological mainly earthquakes and tsunamis and climatic origin, but now social and economic issues are being included to reduce stress in the residents of the Metropolitan Lima Region. In September 2016 in a working meeting with the mayor of Lima, he decided that general manager of Lima impulse the Lima Resilient Programme.

Keywords: Resilient cities; multihazard maps: disaster risk reduction, climatic and geological disasters.

1. Introduction

Thanks to the efforts of the world leaders with a vision of the future, headed by the UN Secretary General, on April 22nd –Earth Day – 2016, a record 171 countries signed a historic agreement to control the emission of Greenhouse Gases (GHGs), in an attempt to reduce the earth's global warming by maintaining the temperature increase below 2 °C by the end of the 21st century. The ceremony was held at the UN Headquarters in New York City. This is an excellent product of the Paris Conference COP 21 of December 2015. However, to reach that goal is not going to be an easy task. It is necessary to take additional key decisions and implement important activities by the year 2030, when it is expected that the GHG emissions will start to be reduced.

During the last few years, a large number of resilient cities initiatives have been set in motion, and is increasing number of cities worldwide are rapidly joining this initiative. It is rational that to make cities resilient to natural disasters, all those projects are focusing on reducing disasters of climatic origin. However, disasters of geological origin such as earthquakes and tsunamis need to be included for cities to be robust. This paper is to be presented at the 16th World Conference on Earthquake Engineering (16WCEE) to be held in Santiago de Chile, in January 2017, and this approach complements the effort of the resilient cities initiative, focusing on disasters of hydrometeorological origin.

In 1998, when El Niño 1997-98 concluded, Peru's Sustainable Cities Programme First Step (PSCP-1S), was started, and it focused on the sustainable city's first attribute: its physical safety. The best argument to convince the then prime minister of Peru and at the same time chief of El Niño Reconstruction Committee – CEREN, and the local authorities of Peru's northwestern cities, was that the flood maps of El Niño 1997-98 of the worst affected cities were carbon copies of those of El Niño 1982-83. Both were extreme, extraordinary events. From 1998 to 2015, the multihazard maps of 175 Peruvian cities were developed, together with land-use plans to reduce disasters, plus four to eight disaster mitigation profiles per city (of the 175 cities mentioned) [1]. The city of Sullana, with a population of 233,615 (2012) has been selected as a case study to innovate and adapt the sustainable city approach, developed from 1998 to 2015, to the resilient city initiative that is to last until 2030 or more according to the Sendai 2015 Declaration.

There have been a large number of disaster reduction studies (in Peru) since the 1980s when UNDRO provided a seed fund to start a tsunami mitigation study [2]. The process of developing the PSCP-1S 1998-2015 has been published elsewhere [3], [4].

The latest investigations to reduce disasters in the Metropolitan Lima Region were made from 2007 to 2013 by the following: Swiss Government cooperation with a Peruvian NGO; European Community cooperation that provided necessary funds to Peru's Civil Defense and UNDP/Peru; and the Japan International Cooperation Agency, JICA, together with CISMID of the National University of Engineering, Lima, Peru [5]. These three projects are in response to a seismic gap existing along some 300 km, parallel to the coastline, centered in the city of Lima and its nearby port of Callao. There is a value of US$450 billion at risk in the Metropolitan Lima Region, according to a report from the Inter-American Development Bank to the Peruvian Ministry of Economy and Finance. If some 7. % of the value at risk is lost, the figure will surpass US$30 billion. That was the total of the direct losses of the 2010 Maule, Chile earthquake. The death toll may also be high depending on the earthquake and tsunami magnitude and scenario, seismic intensity and tsunami run-up, distance of the epicenter to the Lima/Callao area, soil characteristics at the location, and time of day of the event.

According to this background, the Metropolitan Lima Region profile as resilient city is being developed, using extensively as reference the large number of worldwide ongoing resilient city initiatives.

2. Overview of the Ongoing Planning and Implementation of Resilient Cities

During the last few decades, global concern on Climate Change has increased substantially. It started at the Rio Earth Summit in 1992, when the UN Framework Convention on Climate Change (UNFCCC) was adopted for stabilizing atmospheric concentration of greenhouse gases (GHGs). The main objective of the annual Conference of Parties (COP) is to review and update the Rio Convention implementation. COP 3 was held in Japan, where the Kyoto Protocol was adopted, but it did not produce the expected results because the major GHG producing countries did not actually reduce GHG emissions. Consequently, the Earth's temperature has been increasing continuously since the beginning of the industrial age in the mid-19th century, producing a negative impact mainly on the biosphere and in large urban populations and asset concentrations.

Over the last few years a great effort has been made to control GHG emissions and to reduce disaster risk caused by the multiple effects of climate change. There are a number of important global initiatives to reduce disaster from climate change caused by global warming, such as those being promoted by the UNISDR, UN HABITAT, Rockefeller Foundation 100 Resilient Cities, The World Bank, ICLEI Local Governments for Sustainability, and other initiatives, all focused on the Planning and Implementation of Resilient Cities, providing technical and economic assistance to important cities worldwide.

Prof. Rodolfo Saragoni, Chairman of the 16th World Conference of Earthquake Engineering (16WCEE) to be held in Santiago de Chile in January 2017, said: "Disaster risk reduction and management (DRR/M) and climate change adaptation (CCA) applied to Resilient Cities, are receiving priority attention in the Conference Thematic Program presentation and diffusion, during and after the 16WCEE" (Personal communication to the first author, in Lima, Peru, November, 2015).

At present, almost 50 % of the world population of 7,3 billion people (as of April 10, 2016) live in urban areas. It is expected that by the year 2050 the projected world population will reach 9,7 billion inhabitants, 70 % of whom will live in cities, with some benefits such as an increase in the volume of agricultural products and prices, and consequently an improvement in living conditions in rural areas. However, the increasing urban population and asset concentrations is also increasing the physical, social and economic risks, especially in most of the large cities in developing countries, such as Lima, Peru, with 9,75 million people (January 2015).

In the context of the C40 Initiative, "The battle to prevent catastrophic climate change will be won or lost in our cities" emphasizes the importance of developing holistically resilient cities. Some 80 % of GHG emissions globally are generated in cities, produced for example by non-environmentally friendly ground transportation, as individual light motor vehicles that use fossil-fuels; and it is also in cities that a high percentage of the energy produced in most of the countries is consumed.

It is fortunate that at present sociologists, economists, city planners, engineers, and others specialists are joining efforts toward the planning and implementation of resilient cities. During the past few years, initiatives have focused on controlling the GHG emissions, which produce disasters of hydrometeorological origin, which is good. One of the main worldwide objectives was met during the Paris Agreement of December 12, 2015 (COP 21). For the first time, after more than 40 years of negotiations, 195 nations agreed to fight climate change and perform the action and investments required to eventually achieve a low carbon economy for a resilient and sustainable future. Obtaining the desired objective is no easy task. The agreement starts to be implemented in 2020, and GHG emissions will begin to be reduced as from 2030, so climatic disasters will increase in intensity and frequency during the next decade or more. It is rational, therefore, that the planning and implementation of resilient cities is being focused on hydrometeorological disasters affecting high-risk cities.

However, during the past few years the costliest disasters in human victims and material losses have been events of geological origin: earthquakes and tsunamis, one of the main topics of the 16WCEE.

3. Recent Disasters of Geological Origin

The latest disasters with a high death toll and huge material losses have been of geological origin: the 2004 Great Indian Ocean Tsunami, Mw. 9.2, with some 230,000 mortal victims; the Haiti earthquake, Mw. 7.2, a shallow event with its epicenter 18 km from Port-au-Prince, the country's capital city, where the death toll may never be known exactly, as it ranges from 45,000 mortal victims reported by the Red Cross to more than 200,000 declared by the Haiti government; the Feb 27, 2010 Maule Chile earthquake, Mw. 8.8, where the material losses surpassed US$ 30 billion according to the report of the Government of Chile to the coordinator of the UN System in Chile [6][7]; and the 2011 Great East Japan Earthquake (GEJE) or Tohoku-Oki Earthquake, Mw. 9.0, which caused material losses of over US$ 200 billion [8][9]. If the material losses from the Fukushima One nuclear accident are included, that figure is doubled, to include: cleaning due to radiation contamination, and compensation for affected activities such as agriculture, fishing, and manufacture, some 25 km around Fukushima One nuclear site. The death toll was near 20,000; most of the victims lost their lives in the tsunami generated by the earthquake, with a return period of 1000 years.

In the development of resilient cities, holistically, it is necessary to include not only disasters of hydrometeorological origin, such as those caused by Earth's Global Warming, but also disasters of geological origin. To the question: What makes a city resilient? Bruce Watson of The Guardian answers: "While many point to robust disaster defenses others claim social cohesion is what makes a city great. They are both right, and new projects aim to unearth dozens of other factors." [10]. This may be the shortest definition of a resilient city, and a good guide for Peru in its planning of resilient cities.

3.1 Resilient cities in the context of the 16th World Conference of Earthquake engineering (16WCEE)

As an engineering conference, the 16WCEE covers part of the resilient cities' attributes that make them robust, i.e. it mainly takes into consideration cities' physical safety, reducing their risk caused by intense natural events. As previously mentioned, there are a large number of projects focused on the threat from climate change which produces disasters of hydrological origin. The topic of the WCEE covers the theme of disasters caused by natural threats of geological origin: earthquakes and tsunamis. This paper on developing resilient cities focuses on earthquakes and tsunamis that have generated the largest disasters during the last decade. In the multihazard map development base for Peru's Sustainable Cities Programme, all natural threats are included (of geological and hydrometeorological origin). It was started in 1998 in order to reconstruct the northwestern cities of Peru affected by El Niño 1997-98.

4. Adapting Peru's Sustainable Cities Programme 1998-2015 to the Projected Resilient Cities Initiative for 2016 – 2021 (2030)

4.1 The Process of adaptation

Peru's Sustainable Cities Programme 1st STEP (PSCP-1S) focuses on the first attribute of a sustainable city: its physical safety, which is part of a resilient city i.e. being robust.

The action plan is divided into two phases, the first from 2016 to 2021, in order to obtain a tangible result in the next five years: 2021 is the year of the Bicentennial of Peru's Independence; and there is a seismic gap in the subduction zone in front of the Lima Region along some 300 km parallel to the coastal line (see Fig.1). According to experiences of seismic gap in Peru, Chile and Mexico, Nature provides a few five-year periods to liberate the stored energy generating an earthquake of still unknown magnitude but large enough to produce human and material losses; otherwise the seismic gap will remain. So as a working hypothesis to reduce disaster in Lima, we are supposing that the earthquake will occur five years from now to hurry up the preparedness.

The second phase is from 2021 to 2030 according the Sendai Declaration of 2015 United Nations (2015) GAR[11].

4.2 Engineering disaster risk reduction lessons learnt from recent great geological disasters

During the last few years the authors have been busy investigating the most destructive events of geological origin, for professional engineering reasons.

- There was a one-year contract with SENCICO, the section of the Peruvian Ministry of Housing, Construction and Sanitation (MVCS) in charge of developing, approving and enforcing regulations on building construction, from safe city planning to seismic resistant code. The aim was to develop a guideline to design reinforced concrete buildings to resist forces generated by tsunamis, and guidelines for safe city planning in low coastal areas threatened by tsunamis.

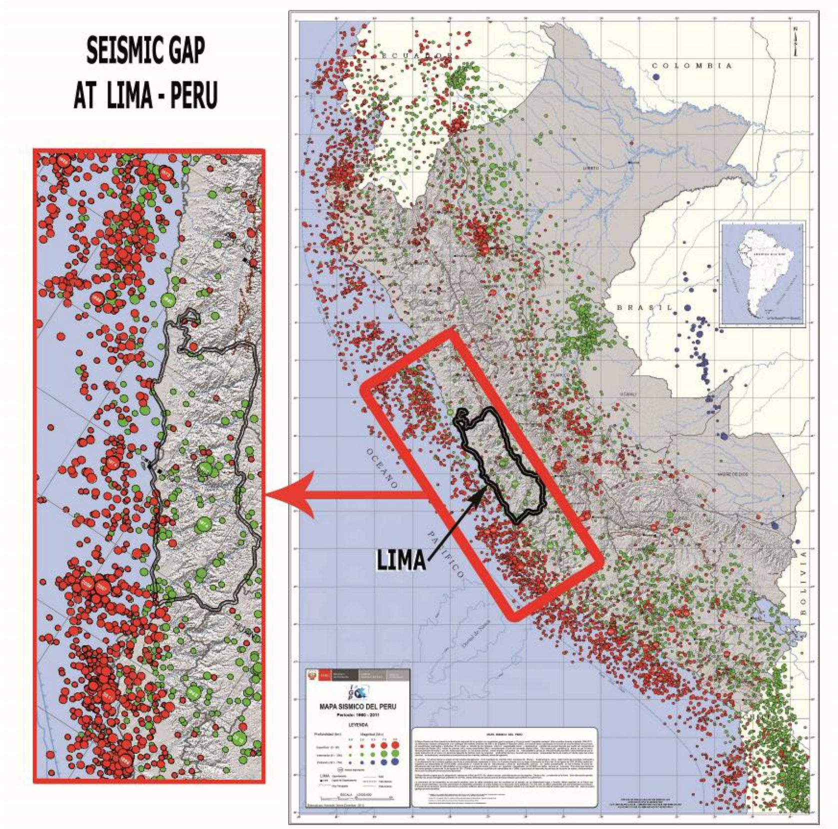

Fig. 1 – Seismic Gap west of Lima capital city of Peru (Source "Seismic Map of Peru" by IGP)

In this reference, investigating the destructive effects of the 2004 Indian Ocean Tsunami the losses caused by the 2010 Maule Chile earthquake and tsunami, and the destruction of the 2011 Tohoku-Oki tsunami on the northeast coast of Honshu, the main island of the Japanese archipelago, was of great help to the authors study objectives.

- The MEXICHEM Corporation Social Responsibility Award granted to the first author provided the opportunity to research the effects of earthquakes and tsunamis on water and sewage system (W&SS). The investigations carried out in New Zealand, on the W&SS of Christchurch, the capital city of the country's South Island, where damage had been caused by the series of earthquakes of 2010 and 2011, provided rich and interesting data of how buried pipelines behaved in the event of soil liquefaction, because one third of the city is developed on swamp areas [12].

  During the 2010 Maule Chile and 2011 Tohoku Japan earthquakes, because of their long duration, the pore water pressure was gradually increased. In Chile this caused severe soil liquefaction along the Chilean coast, twice the length of the activated geological fault [13]. In Japan, 300 km south of the 2011 earthquake source, along the coast of Tokyo Bay, liquefaction occurred at Mihama, a suburb of Chiba City [14]. It is the consensus of technical scientific communities that the main cause of buried pipe damage is permanent soil deformation caused by soil liquefaction; and a second cause is the great velocity of transient ground vibration. The damage caused to the pipeline system in New Zealand 2010-2011, Chile 2010 and Japan 2011 followed this pattern that strongly depends on soil geotechnical characteristics; such characteristics may be investigated in advance and so strategies and practical engineering measures can be developed to protect buried pipelines and other components of W&SS.

- Consulting jobs on the seismic and tsunami hazards for two important engineering projects, at present under construction - Lima Subway Line No 2 and a tunnel below Lima International Airport's Second Runway - provided the opportunity to study the results of two important technical scientific advances developed in the past few years:

- Co-seismic horizontal and vertical deformation of the earth's surface occurring simultaneously with the earthquake and tsunami generation. According to the Science publication of June 17, 2011 of the American Association for the Advancement of Science, AAAS, the co-seismic measurement of the earth crust deformation and its interpretation during the Tohoku, Japan earthquake, was one of the outstanding scientific advancements in the year 2011, Simons Mark, et al (2011) [15]; and
- Paleotsunami investigation, which was given great attention by the international community after the 2004 Indian Ocean great tsunami.

Before 2011, because of the scarcity of tsunami historical data, it was practically impossible to determine the tsunami run-up for the Metropolitan Lima area, where those two engineering projects are under construction at present (2016), for tsunamis with return periods of 475 and 1000 years, information that was required according to the terms of reference for the development of the construction project.

4.3 Summary of the lessons learnt from the studies of great disasters of geological origin occurred in the last few years.

1. Building response to earthquakes, the international experience

In general, in Japan and the USA, those buildings designed with relatively new codes after the 1980s had responded as expected to earthquakes. The Maule Chile 2010 and Tohoku Japan 2011 events left interesting lessons. In Chile 2010 a few buildings collapsed, but this depended more on the wrong structural concept to resist horizontal seismic forces. However large number of buildings suffered severe damage [7]

Both in Chile 2010 and Japan 2011, seismic isolation and energy dissipation devices responded as expected and no damage was reported. In Chile for a seismic intensity of VIII – VII MMI and in Japan, for a seismic intensity up to X MMI in Sendai city, where no damage was reported in buildings' structural elements or in their non-structural elements and contents. In the 2011 Tohoku, Japan earthquake, practically no building damage was reported outside the tsunami inundation area.

2. Building Response to tsunamis

The Building Research Institute (BRI) of the Ministry of Land Infrastructure, Transport and Tourism (MLIT) of Japan made extensive investigations on different types of constructions exposure to the Tohoku-Oki tsunami. This was reported by the Office of the Japanese Prime Minister and the World Bank Group (2012) [8], as well as on the web site of BRI/MLIT (2011 – 2012).

Wooden houses were totally destroyed by the tsunami. They were easily pulled off their foundations, converting the debris into very hazardous floating projectiles that killed many people and increased the material damage. A number of three to four-story reinforced concrete and steel buildings were overturned. The buildings' connection to their foundations was not strong enough to take the horizontal tsunami forces. A number of reinforced concrete buildings over six stories in height resisted the seismic and tsunami solicitation well and were useful as tsunami refuge centers with vertical evacuation. Buildings with steel structural skeletons remained vertical, but facades and partition walls were torn off from the resisting structures.

During the 2004 Great Indian Ocean Tsunami some reinforced concrete buildings, such as hotels in Thailand, remained undamaged by the tsunami. A mosque, with a tsunami height of 9 m, was found to have sand on its roof, but no significant damage was reported. In both cases, the first level had ample openings allowing the free pass of the tsunami waves.

3. Tsunami erosion to building foundations and buried water pipelines

One of the most interesting and useful investigations was that carried out by an American professional engineer, Mathew J. Francis (2006) [16]. His study focused on the tsunami erosion depth at different locations near the source at the northwest of Sumatra Island and at distant locations such as Thailand and Sri Lanka. In the last-named location, the tsunami effects were very severe because the directional effects of the tsunami wave, traveling east to west impacted Sri Lanka island directly. It was found, after the investigation, that the maximum erosion depth was 2.0 m at hundreds of sites -- except in Banda Aceh, where the tsunami coming from the east had surpassed a hill elevation. At the other side of that hill the tsunami erosion almost reached 4,0 m, because of the steep slope of the hill. The tsunami wave gained in velocity and had more erosional power. It is also interesting to point out what happened in the Russian Kuril Island, located east of the Kamchatka peninsula. During the tsunamis that occurred on November 15, 2006, Mw 8.3, and January 13, 2007, Mw 8.2, the material deposited inland was less than the eroded material, sand and dirt. In some of the erosion canals, the width was as much as 7.0 to 8.0 m and they were more than 2 m deep. The Russian and American scientists did not mention it, but on observing the photo, behind the severely eroded area, we see a hill. It is assumed that the tsunami ran up the hill and during the recession it gained in velocity and erosion power [17].

4.4 Peru's tsunamis of 2001 and 2007 and the controversy of the 1998 Papua New Guinea tsunami height

Before the occurrence of the 2001 earthquake (Mw 8.4) and tsunami in Peru the UN / Peru's Civil Defense (INDECI) Regional Seismic Scenario was developed in southwest Peru, under the frame of the "Disaster Mitigation Programme in Peru 1992-95" [18]. At Peru's southwest coast, the continental platform between the coastal line and the Lima trench is narrow. This is where the tsunamigenic earthquakes are generated, so the path of the tsunami from its origin to the coast is short. According to an estimation made by a Civil Engineering professional thesis at the UNI, the results indicated that the first wave should arrive in some 10 minutes and the run-up waves in 8 m to 10 m. According to USGS, the tsunami height at the coast was 6,0 m. Witnesses reported that the 1st wave receded some 10 minutes after the occurrence of the earthquake. Some 65 people from the southern part of Camana walked onto the dry sea bottom. When the second wave arrived ten minutes later, those people lost their lives. They did not know that a tsunami generated in 1946 in the Aleutian Islands, in Alaska, killed about the same number of people in Hawaii under similar circumstances. In Camana the maximum penetration was 600 m (USGS), consuming 1% of the tsunami energy due to friction on agricultural land.

After the 2007 Pisco Peru earthquake (Mw 8.0) and tsunami, the tsunami wave heights on land on the stretch of some 15 km from Tambo Mora, Pisco, San Andres and Paracas were measured by the Peruvian Navy, Directorate of Hydrology and Navigation (DHN) [19]. The estimation of tsunami height for those places had been made by a Master of Science CE thesis at UNI, six years before. The event's estimated measured run-up had differences of ±5% with the physically measured run-up. The tsunami height was in the range of 1,95 m to 2,10 m as shallow sea water goes far from the coastal line to the bathymetry at 100 m depth.

Based on the experience at the University of Tohoku studies of the 1933 M 8.4 and 1896 M 8.5 Sanriku earthquakes and tsunamis, the Yamaguchi formula $h = 12.3\ e^{-0.067\ (D)}$ was developed which produced acceptable results in the Arequipa 2001 event and good agreement in the Pisco 2007 Peru tsunami, where h(m) is the wave height at coastal line and D(km) is the distance from the coast to the 100 m depth bathymetry line.

There is controversy with regard to the cause of the tsunami wave's unusual height on the coast of Papua New Guinea during the earthquake and tsunami of July 17, 1998, Mw 7.1, depth 6 km, epicenter near the coast (USGS). While some researchers, such as Synolakis C et al. (2002) [20] stated that the cause of extreme run-up amplitude was due to a submarine landslide, other investigators disagree with that idea. In the USGS home page article, Descriptive model of the July 17, 1998 Papua New Guinea Tsunami it was stated that "It is possible that the relatively deep near shore contributed to the unusual height of the tsunami." By applying the Yamaguchi formula, the area bathymetry was obtained from Davies H.L. et al. [24], for D = 2.29 km, the tsunami height is 10.5 m (see Fig. 2). In Fig. 3 is indicated the zone of total destruction. The numbers indicate the time the wave arrived at the coast, shown as minutes after the occurrence of the earthquake.

At the Tohoku east coast, during the tsunami of 1896, 1933 and 2011, the highest tsunami height occurred where the 100 m ocean depths are closest to the coast (see Fig. 4).

4.5 Summary of Peru's Sustainable City Programme 1998 - 2015

The Sustainable City Programme (SCP) UNDP/Peru Civil Defense was initiated in 1998. The strongest argument to convince central and local authorities was provided by Nature itself, as the inundation maps of the main cities affected by El Niño 1997-98 were practically carbon copies of those affected by El Niño 1982-83.

Multihazard maps are the main tool for reducing disasters in urban areas. They include all the natural and technological hazards that threaten the cities and their future expansion areas. The microzonation investigation includes earthquakes, flooding due to climatic effects, tsunamis and landslides.

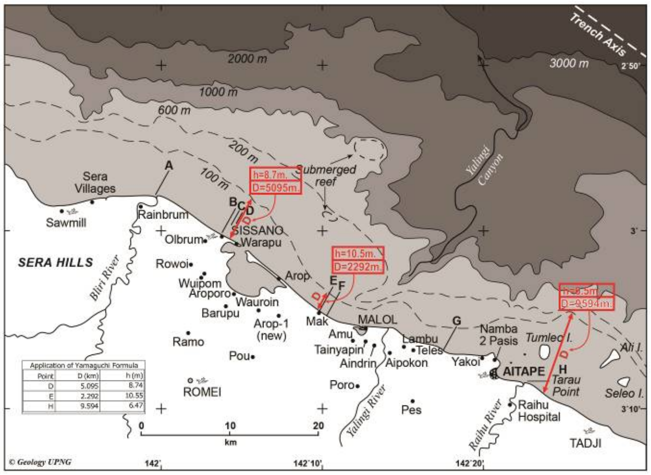

Fig. 2 Bathymetric map of the affected area and distances from the coastal line to the 100 m depth line (Calculation in red by authors, source of bathymetry Davies H.L. et al. [21])

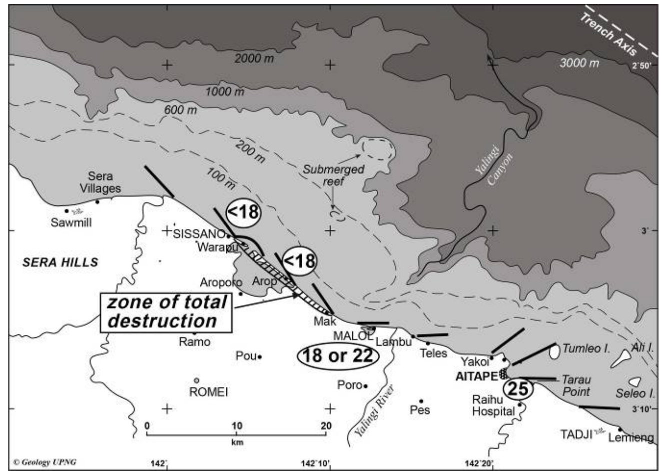

Fig. 3 "The heavy lines indicate the approximate alignment of the wave front as it intersects each section of the coast." At the zone of total destruction, a tsunami wave 10 to 15 m in height killed nearly 2000 people (Source as Fig. 2)

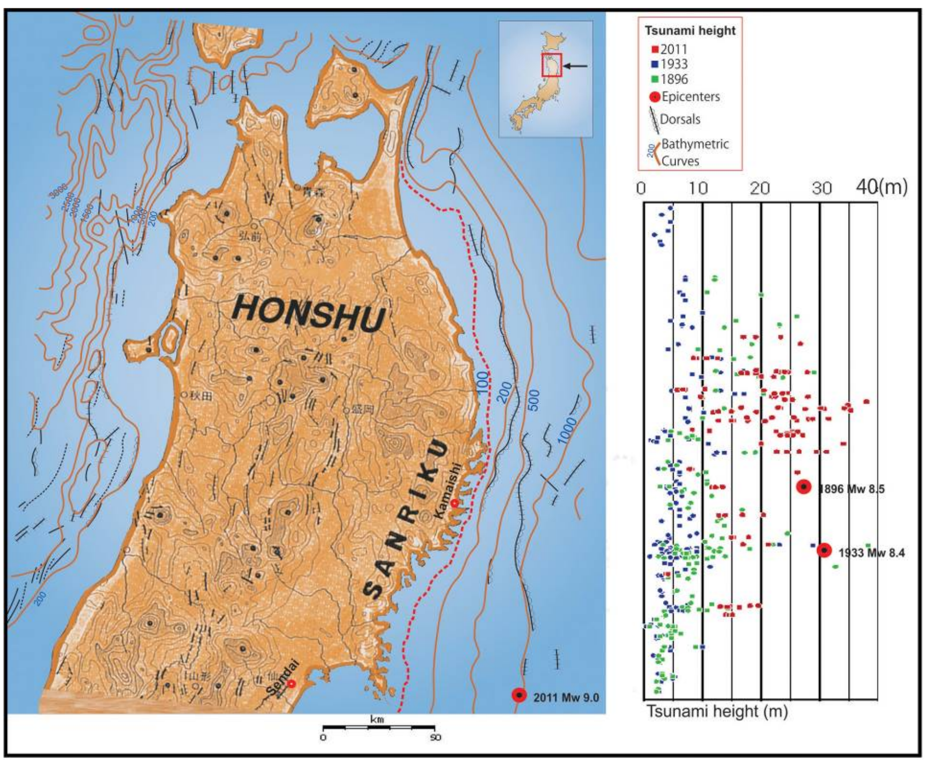

Fig. 4 Tohoku, Japan's east coast. The Sanriku tsunamis of 1896, 1933 and 2011 also provide valuable information concerning the epicenters of those three earthquakes and tsunami heights. Notice that for those tsunamis the maximum height occurred where 100 m. bathymetric depth is closest to the coast [8].

The recent Maule, Chile 2010 and Tohoku, Japan 2011 earthquakes have shown that soil liquefaction was the main cause of material losses. In the Peru 2001 and 2007 earthquakes, which occurred in very dry areas, soil liquefaction took place only in a few locations, indicating that the presence of water is important for soil liquefaction to occur.

In Peru, the state-of-the-art in microzonation investigation was reached in the 1970s, when the Japanese Scientific Mission developed the multihazard map of the city of Chimbote; and in 1980s the United Nations International Atomic Energy Agency (UN/IAEA), Vienna, safety standard was applied for the site investigation of a small experimental nuclear reactor located near Lima, Peru.

In order to reduce cost and time, the seismic microzonation methods were simplified for mass application. From 1998 to the present, multihazard maps and land-use plans to reduce disasters for 175 Peruvian cities have been developed, with the aim of protecting more than 7,5 million people all over the country.

In 2021 Peru will be celebrating the bicentennial of its independence. The goal is to reach this milestone with safer cities for Peruvians to live in. The Hyogo Framework for Action was taken into consideration. The Sendai Disaster Risk Reduction Framework is being applied, focusing on where and how to locate lifeline networks such as water and energy; and essential facilities in the event of disasters, such as hospitals and school buildings. Peru's SCP has received important international and national recognitions.

4.6 Adaptation of Sustainable Cities to Resilient Cities in Peru

Information available includes the results of multihazard maps, the land-use plans to reduce disasters, and four to eight disaster mitigation profiles per city. The existing information pertains to 175 large, medium, and small Peruvian cities, ranging from more than a million people, as in Arequipa city, hundreds of thousands in capital cities of regions, to 30,000 to 50,000 inhabitants of district capital cities. The advancement in the implementation of SCP 1998 – 2015 was not as expected, for two main reasons:

- Lack of adequate technical and administrative capacities of the local governments.
- There was no specific funding to implement the SCP; however, Peru's Prime Minister's Office continuously provided the necessary financing for the investigations carried out from 1998 to 2015. Two successive central governments acted coherently during the presidential periods of 2006 – 2011 and 2011 – 2016.

On December 17, 2010, State Policy No. 32 was unanimously approved: this Policy is Disaster Risk Management, Education, whereby disaster risk reduction was made compulsory at all levels, from primary school to universities; significantly, it placed emphasis on city planning taking climate change into consideration, in keeping with the global trend.

On November 1, 2012, Supreme Decree of the Prime Minister's Office PCM No 111 was promulgated, which makes it compulsory for the central, regional and local government officials to apply State Policy No 32. It is accompanied by adequate financing of disaster reduction projects.

Private mining corporations have successfully developed three new sustainable cities to be occupied by their personnel. The new cities are: El Pinar, Nueva Fuerabamba and Nueva Morococha with important capital investment from Switzerland, Canada, USA, Australia, China and Japan.

The new city of Olmos was initiated in April 2016 by the MVCS to house up to 100,000 people. It is located in the core of a new irrigation project of 40,000 ha + 40,000 ha of new agriculture land. The authors intervened as consultants reviewing the multihazard maps of those projects.

4.7 The city of Sullana as a case study for adapting sustainable cities to a resilient city approach.

Why the city of Sullana? Because during El Niño 1982-83, this was the city that suffered the worst destruction and had the heaviest death toll. An important disaster mitigation project was developed, which responded well to the El Niño 1997-98. Both events were extreme and extraordinary.

The core of the city of Sullana develops along the axis of the valley where its cross-section is a very open "V" shape of a 3.4 km-long upstream valley. Heavy rain in those days caused a large volume of water to be dammed by the Pan-American highway platform. When the height of the water reached the level of the covering asphalt, this was peeled off and the granular soil platform was rapidly eroded; a high wave of water ran along the axis of the valley destroying everything within a width of 100 m to 350 m, including buildings and infrastructure such as water and energy facilities.

Along the axis of the valley, a canal–road was built to hold the water volume of the 1982-83 El Niño. When the El Niño 1997-98 occurred, the peak volume slightly overflowed the canal, so the residents of the new buildings had to use sandbags or planks of wood to prevent the water from getting into their homes through the front door. It was considered that the canal-road had behaved as expected, since both El Niños had been extreme events. East of the city's built-up area, there was agricultural land that the authorities were planning to use for park and recreation areas, but this had not yet been executed. It was a pending project that needed to be implemented, adding solutions to social economic problems, so that the project to be developed would make the city of Sullana into a resilient city. The Sullana city urban planning staff of the Municipality of Sullana are receiving advice from the authors of this paper.

5. Metropolitan Lima Region Resilient City Profile

The Metropolitan Lima Region (LMR) covers an area of 2, 819 km2 or 281,900 ha, including the nearby port of Callao, by far the country's most important, as over 70% of the country's import/export trade uses its facilities. In 2015 the LMR had a population of 9,45 million people.

During the May 1940 earthquake, magnitude Richter 8.2, Peru's capital city had a population of 600,000 people. The rapid population growth was mainly due to large migration from the Andean cities and rural areas. In 1950, on Christmas Eve, the first "invasion" of squatters occurred on aeolian loose sand. The new settlement was named Ciudad de Dios (God's City), because it occurred on December 25. Since then, the non-planned urban occupations have been occurring in crescendo. During the last few decades the high slopes of aeolian sand hills have been occupied. This is also happening in ravines located in the low medium reaches of the Rimac River, where violent debris flows with large stones had destroyed hundreds of brick dwellings. So, in both cases, the scenario of future disasters is being created.

According to a report from the Ministry of Housing, Construction and Sanitation (MVCS), some 70% of the dwellings are not engineered constructions, so most of them are vulnerable to earthquakes. The old sectors of Lima existing in 1940 are adobe constructions weakened by the accumulative effect of past earthquakes and the soil humidity due to broken water and sewage pipes. A number of investigations of those problems have been carried out during the last few decades, which need to be reviewed and updated systematically, in order to apply them to make LMR more robust.

The nearby port of Callao was destroyed by a tsunami on October 28, 1746; of 4,000 inhabitants, and only 200 saved their lives. An investigation carried out by the authors found that the tsunami height on shore was 7-8 m for a return period of 475 years, and 10 m for 1000 years, verified by a simulation performed by researches of the Tohoku University and Peruvian universities, using the historical information from the macroseismic area of the 1746 earthquake and tsunami. In three virtual locations, two in Callao were 10 m high and at the Lima cliff 22 m [22]. The tsunami height in Callao agrees with the research results of authors as consultants of two important civil works at present under construction in Lima - Callao.

In the development of the MLR city profile, there are cases that are proving useful in this respect. For example, the Tokyo, Japan, city profiles, in addition to climatic disasters, address earthquakes as the main concern, because the city was destroyed by the 1923 Tokyo earthquake and fire. Los Angeles CA, USA, is located in a very dry area, as is Lima, so the saving of the drinking water supply and the effects of earthquakes have priority in the action plan. The Kyoto Japan Climate and Disaster Resilient City Profile considers five dimensions of Resilience. Natural (environment and disasters), Physical (electricity, water supply, solid waste, roads, housing, and warning system), Social (the population, health, education, social capital), Economic (livelihood: income, employment, household assets, savings, insurance, budget subsidy) and Institutional (organizations, development plan, internal and external investigation networks). They are included in a Matrix, together with their indicators, and it is possible to grade them. Santiago de Chile has a geological surface quite similar to that of Lima, since it was deposited on the same geographic environment by the Mapocho River and Rimac River respectively; the building types and seismic codes are quite similar, so it may be a good idea to exchange knowledge and experiences.

Finally, the Maule city, Chile, resilient profile indicates that one of the most critical problems was that which occurred during the Chile 2010 earthquake, when their water and sewage systems were completely destroyed, as well as the drinking water source at a river. In LMR, SEDAPAL provides drinking water for the city and has set in motion a series of activities to reduce the vulnerability of the Lima Water System. The authors are coordinating activities with the mayors of Sullana and the Metropolitan Lima Region, since these are the authorities mainly responsible for ensuring that their cities will be resilient.

6. Concluding Remarks

From 1998 to 2015, Peru's Sustainable Cities Programme (PSCP) was developed for 175 cities. The studies focused on the disaster risk reduction of these cities in reference to events of geological and climatic origin. Since early 2015, the main purpose of the studies was how to adapt the PSCP to the resilient city initiative, which covers not only the cities' physical aspects but also social and economic issues. The task is immense and complex; it will be implemented giving priority to each city's crucial problems.

For example, for most of the Peruvian cities personal safety is the main concern of all the inhabitants, because delinquency is on the increase. For LMR, public mass transportation is critical as the large number of light transportation units has increased largely surpassing the capacity of streets and avenues. Lima has planned six subways for mass transportation. Line 1 is functioning with no problem. Line 2 is under construction. Lines 3 to 6 might be concluded during the next decade. Reducing traffic congestion is an major economic and social problem that needs to be included in the RCI. There are health problems in Lima mainly because of contamination caused by gases emitted by private automobiles and large bus fleets.

For other Peruvian cities, it is necessary to foresee future major transportation problems and to find a rational solution, which will mean great savings of money and time for all the users.

This short list presents the main problems that need to be addressed and require priority solutions.

Because of terrorist activities in the 1980s, the economic development was greatly hindered, so costly transportation construction has been postponed for a few decades since the early 21st century. Thanks to reforms carried out during the 1990s, the maintenance of the economic model and the high prices of commodities, the main Peruvian exports, the country's GNP has continuously and significantly improved so the resilient cities initiative may be financed.

7. Acknowledgements

To Peru's Prime Ministers in office from 1998 to 2015, for continuously providing funds for the PSCP-1S, to CEREN and Peru's Civil Defense that conducted the PSCP from 1998 to 2001 and from 2001 to 2015, respectively, and nominated the first author as chief technical advisor of the PSCP-1S; to UNDP/Peru, which provided technical and some financial assistance in 1998 to 2015. To the Swiss Government, the European Union, JICA and CISMID/UNI, which conducted disaster risk investigations and management in Metropolitan Lima from 2007 to 2013. To UNISDR for nominating the first author member of the Advisory Panel 2010-2015 Campaign Partners Making Cities Resilient. To MEXICHEM for providing the opportunity to investigate how to protect water systems from destructive natural events.

8. References

[1] Kuroiwa J (2014): Peru sustainable (resilient) cities programme 1998 - 2012 Its application 2014 – 2021. *4th International Conference on Building Resilience, 8- 11 September 2014*. Salford Quays. United Kingdom.

[2] Delgado A, Garcia C (1982): Evacuation Plan for Tsunami threatened cities from Pucusana to Callao. *Professional thesis of Civil Engineering. National University of Engineering*, Lima, Peru.

[3] Kuroiwa J. (2005): Disaster Reduction. Living in harmony with Nature. Book of 496 p. *2nd UN World Conference on Disaster Risk Reduction*, Kobe, Hyogo, Japan. January, 2005.

[4] Kuroiwa J, Delgado A (2012): Resilient cities – an effective way to reduce disasters. *Proc. 15 WCEE*, Lisbon, Portugal. 24 to 28 Sept. 2012.

[5] Yamazaki F, Zavala C (2012): SATREPS Project on Enhancement of Earthquake and Tsunami Disaster Mitigation Technology in Peru. *Journal of Disaster Research*, Vol. 8, Nº 2.224-234, 11p.

[6] University of Chile (2012): 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.

[7] EERI. Earthquake Spectra (2012): Special Issue on the 2010 Maule Chile Earthquake. *Guest Editors J.P. Moehle and J.D. Frost*. Vol 28, Number S1. June 2012. Vol of 642p.

[8] Government of Japan, GFDRR, The World Bank (2012): Learning from Megadisaster 2011. The Great East Japan Earthquake. *Proc. International Seminar*, Tokyo, Oct. 2012.

[9] EERI. Earthquake Spectra (2013): Special Issue on the 2011 Tohoku-Oki Earthquake and Tsunami. *Guest Editors James More and Richard Eisner*. Vol 29, Number S1, March 2013. Vol of 499 p.

[10] WATSON B (2014): The Guardian. What makes a city resilient? *The Guardian*. 23 January 2014.

[11] United Nations GAR (2015): Global Assessment of Disaster Risk Report of 300p. www.preventionweb.net/gor/

[12] Cubrinovski M, Henderson D, Bradley B (2012): Liquefaction Impacts in Residential Areas in the 2010-2011 Christchurch Earthquakes. *Proc. Intern. Symposium on Engineering Lessons Learned from the 2011 Great East Japan Earthquake*, Tokyo, Japan.

[13] Verdugo R, Gonzales J, Gonzales V, Torres A (2012): Características y efectos del fenómeno de licuefacción in Mw = 8.8 Chile. Earthquake of Feb. 27, 2010.*In University of Chile publication of 323p*. In Spanish pp. 63-95.

[14] Nakai S, Sekiguchi T (2012): Damage due to Liquefaction During the 2011 Tohoku Earthquake. *Paper No. M-1. UNI, CISMID*, Peru.

[15] Simons M, Minson S, Sladen A, Ortega F, Jiang J, Owen S, Meng L, Ampuero JP, Weis S, Chu R, Helmberger D, Kanamori H, Hetland E, Moore A, Webb F (2011): The 2011 Magnitude 9.0 Tohoku-Oki Earthquake: Mosaicking the Megathrust from Seconds to Centuries. *Science Vol 332 17*. June 2011.

[16] Mathew JF (2006): Tsunami Inundation of Roadways, Bridges and Foundations. Observations and Technical Guidance from the Great Sumatra Andaman Tsunami. *EERI/FEMA NEHRP 2006 Professional Fellowship Report.*

[17] Science Daily (Oct. 28, 2009): First Detailed Documentation of Tsunami Erosion. http://www.sciencedaily.com/releases/2009/10/091028112803.htm

[18] Kuroiwa J (2002): Sustainable Cities, a Regional Seismic Scenario, and the 2001.06.23 Arequipa Peru Earthquake. *Special Issue of Natural Hazard Review*, November de 2002 ASCE, Reston, Virginia, USA.

[19] Ministerio de Defensa. Marina de Guerra del Perú. Dirección de Hidrografía y Navegación (2007): *Report Post Tsunami* August. 2007, 46p.

[20] Synolakis, CE, Bardets JP, Borrero C, Davies HL, Okal EA, Silver J, Sweet, Tappin (2002): The slump origin of the 1998 Papua New Guinea Tsunami. *Proc. Of The Royal Society, A Mathematical, Physical and Engineering Sciences*, Published 8 April 2002.

[21] Davis HL, Davies JM, Perembo RBC, Lus WY (1998): The Aitape 1998 tsunami: Reconstructing the event from interviews and field mapping. For a special issue *of Pure and Applied Geophysics on the Aitape Tsunami*.

[22] Jimenez C, Moggiano N, Mas E, Adriano B, Koshimura S, Fujii Y, Yanagisawa H (2013): Seismic source of 1746 Callao Earthquake from tsunami numerical modelling. *Journal of Disaster Research*. Vol.8 No.2, 2013, 8p.